

**GUIDEBOOK TO THE GEOLOGY
AND ENVIRONMENTAL CONCERNS
IN THE TRI-STATE LEAD-ZINC DISTRICT,
MISSOURI, KANSAS, OKLAHOMA**

ASSOCIATION OF MISSOURI GEOLOGISTS

**33rd ANNUAL MEETING
AND FIELD TRIP**

**JOPLIN, MISSOURI
SEPTEMBER 26-27, 1986**

**JOPLIN FIELD, MISSOURI
WEBB CITY, MISSOURI
GALENA FIELD, KANSAS**

**PICHER FIELD, OKLAHOMA
ORONOGO, MISSOURI
BAXTER SPRINGS, KANSAS**

SPONSORED BY:

**WALDEMAR M. DRESSEL DANIEL R. STEWART
DIVISION OF GEOLOGY AND LAND SURVEY:
DEPARTMENT OF NATURAL RESOURCES
DEPARTMENT OF GEOLOGY AND GEOPHYSICS,
UNIVERSITY OF MISSOURI-ROLLA**

FIELD TRIP COMMITTEE:

**RICHARD D. HAGNI (CHAIRMAN) WALDEMAR M. DRESSEL
DANIEL R. STEWART MICHAEL C. MCFARLAND
JAMES C. BROWN, JR. ALICE C. FUERST
JAN C. TUPPER (LOCAL ARRANGEMENTS)**

40114767

Site: Oronogo Dunes
ID #: MOD 986 686 281
Break: 11. 11
Other: 9.24.86



SUPERFUND RECORDS

ASSOCIATION OF MISSOURI GEOLOGISTS
33rd ANNUAL MEETING AND FIELD TRIP

September 26 and 27, 1986

GEOLOGY AND ENVIRONMENTAL CONCERNS IN THE TRI-STATE ZINC-LEAD DISTRICT,
MISSOURI, KANSAS, OKLAHOMA

EXECUTIVE COMMITTEE:

PRESIDENT	DICK HAGNI
PRESIDENT-ELECT	JERRY VINEYARD
PAST PRESIDENT	DAVE HOFFMAN
SECRETARY-TREASURER	BRUCE AHLER
MEMBER-AT-LARGE	IRA SATTERFIELD

GUIDEBOOK EDITOR:

DICK HAGNI

FIELD TRIP COMMITTEE:

DICK HAGNI (CHAIRMAN)
WALLY DRESSEL
DAN STEWART
MIKE MCFARLAND
JIM BROWN
ALICE FUERST
JAN TUPPER (LOCAL ARRANGEMENTS)

SPONSORED BY:

WALDEMAR M. DRESSEL
DANIEL R. STEWART
DIVISION OF GEOLOGY AND LAND SURVEY-DEPARTMENT OF NATURAL RESOURCES
DEPARTMENT OF GEOLOGY AND GEOPHYSICS, UNIVERSITY OF MISSOURI-ROLLA

TABLE OF CONTENTS

	Page
Road Log for Friday Afternoon Field Trip	1
¹ Michael C. McFarland ¹ , and James C. Brown, Jr. ¹ , Daniel R. Stewart ² ¹ Division of Geology and Land Survey, Department of Natural Resources Route 1, Box 158, Webb City, Missouri	
Road Log for Saturday Morning Field Trip	8
Waldemar M. Dressel, 307 Christy Drive, Rolla, Missouri	
A Brief Description of the Historical, Ore Production, Mine Pumping, and Prospecting Aspects of the Tri-State Zinc-Lead District of Missouri, Kansas, and Oklahoma	16
Daniel R. Stewart, Route 1, Box 158, Webb City, Missouri	
A Summary of the Geology of the Ore Deposits of the Tri-State District, Missouri, Kansas, and Oklahoma	30
Richard D. Hagni, Department of Geology and Geophysics, University of Missouri-Rolla, Rolla, Missouri	
Post-Mining Hazards of the Kansas-Missouri-Oklahoma Tri-State Zinc-Lead Mining District	47
Waldemar M. Dressel ¹ , Michael C. McFarland ² , and James C. Brown, Jr. ² ¹ 307 Christy Drive, Rolla, Missouri; ² Division of Geology and Land Survey, Department of Natural Resources	
Environmental Hazards and Corrective Actions Associated with the Tri-State Lead and Zinc Mining District, Kansas and Oklahoma	55
Alice C. Fuerst, U.S. Environmental Protection Agency, Region VII, Kansas City, Kansas	
Effects of Abandoned Lead and Zinc Mines and Tailings Piles on Water Quality in the Joplin Area, Missouri	60
James H. Barks, U.S. Geological Survey, Rolla, Missouri	
Result to Date of CUSMAP Studies in the Joplin Quadrangle	70
Pieter Berendsen, Kansas Geological Survey, Lawrence, Kansas	

ROAD LOG FOR FRIDAY AFTERNOON FIELD TRIP

September 26, 1986

Estimated Total Time - 4 hours (excluding Museum)

Road Log-Drive Time 1.5 hours

Michael C. McFarland¹, James C. Brown, Jr.¹, and Daniel R. Stewart²

¹Division of Geology and Land Survey
Department of Natural Resources
P.O. Box 250
Rolla, Missouri 65401

²Route 1, Box 158
Webb City, Missouri 64870

MILEAGE

- 0.0 Depart from Holiday Inn, head north on Rangeline Dr. (Hwy. 71).
- 2.35 Jct: Rangeline Dr. and old Hwy. 66 (E. 7th St.). Turn right and head east on old Hwy 66.
- 5.35 Tri-State Motor Transit Company: The land on the north side of the road has been reclaimed. Open shafts have been backfilled and chat piles leveled to prepare the grounds for a large truck depot and office complex. A huge "sheet ground" mine - the Wilson-Baltic Mine - lies flooded 200 feet below the surface here. Reclamation took place circa 1977-78.
- 6.35 Jct: old Hwy. 66 and gravel road beyond the town of Duenweg. Turn left and head north on gravel road.
- 6.85 Mo-Pac RR crosses gravel road. Note pipeline on west side of road, adjacent to railroad. Mine waters from Overland Mine west shaft, about $\frac{1}{2}$ mi. northwest of this point, are pumped to the surface and piped to the Atlas Powder Co. (about 1 mi. east of this point) for industrial use.
- 7.35 Jct: Gravel road and paved road. Turn left and head west on paved road.
- 7.65 Mo-Pac RR crosses paved road, Overland Mine, West shaft, source of piped water is located just south of paved road. Also located in this area is the Athletic Mine, whose mine waters are pumped through an underground pipeline to the W. R. Grace Fertilizer Company Plant about $1\frac{1}{2}$ miles east of this area.
- 8.35 Jct: Paved road. Turn right and head north.

9.10 STOP 1: Independent Gravel Co., Vogie Plant entrance on right. At this facility, chats and boulders from mine waste piles are crushed and screened to several commercial sizes and sold as blasting sand, roofing granules, pipe coatings, and filter sand. The plant utilizes mine waters from the Vogie Mine, which underlies most of this area, to transport and wash the chat as it passes through the crushers and screens. Water is pumped from one of the original mine shafts, makes its journey through the plant, and is then discharged into another mine shaft. The water is circulated enough while passing through the flooded mine workings so that it emerges quite clear by the time it is pumped again. Also of interest at this site are two closed shafts. In one case railroad rails and concrete slabs have been set in place over an open shaft. In the other instance a simple concrete pad has been poured over a metal grate, producing a true seal. These types of safeguards are both economical and effective.

9.40 Jct: Hwy. AA and paved road. Turn right onto AA.

10.40 Jct: Hwy. AA and gravel road. Turn left.

10.90 STOP 2----Griesemer Quarry (Joplin Stone Co.)

Good section of Upper Warsaw beds A through J. The quarry exposes a 50-foot face that is representative of non-cherty facies of the Warsaw limestone. These non-cherty facies are rather rare, but do occur in a few areas. The limestone is rather dark gray due to the staining from petroliferous matter. In some portions of the quarry actual fluid petroleum can be noted. The Missouri Highway Department especially favors this limestone for blacktop aggregate because of its inherent petroleum content. The north wall of the quarry displays embryonic sink structures in their early stages of formation. Note that pitch and flat structures, which are similar to those that are important ore-containing structures in the Wisconsin-Illinois district, have formed by underground rock dissolution.

11.40 Jct: Turn left on gravel road.

12.40 Jct: Hwy. AA and gravel road. This is the town of Prosperity. Stop, look and continue west across Hwy. AA to the Holy Smoke Pit entrance.

12.90 Road crosses "miners canal". At the height of active mining, circa 1910, in the Duenweg-Webb City-Oronogo fields, numerous drainage canals were constructed to divert surface water and pumped mine waters away from important production-shaft areas. (Note brick-type pattern in canal banks.) These canals remain intact today as wet-weather tributaries of Center Creek.

13.00 STOP 3. HOLY SMOKE PIT entrance on right. The Holy Smoke Pit is an example of a mine whose roof has caved in, connecting the surface with the underground workings and allowing mine waters to invade the surface depression. Waste piles have also descended into the pit, and their tops can be seen in the north end of the pit during low water level.

A dished area, within the Chat/boulder pile south of Holy Smoke Pit, indicates a mine shaft exists below the pile. Material is slowly settling and subsiding into the shaft, thus producing the surface "funnel". Backfilled shafts that "re-open" are common throughout the district.

- 13.50 Jct: Gravel road and Hall St. Turn right and head north on Hall St.
- 14.65 Jct: Hall St. and Hwy. 71. Turn left and head west on Hwy. 71.
- 14.75 Jct: Hwy. 71 and Main St. (Hwy. D). Turn left and head south into Sucker Flats Pit Area. This open pit measures 1000 X 700 feet, is 80 feet deep to water level, and total pit depth is about 220 feet. Rich ore bodies, called "circles", developed about filled-sink and other dissolution structures. Pennsylvanian strata can be seen in the pit's walls as well as Mississippian bedrock. This site has been included in a city park in memory of the zinc miners. The Kneeling Miner and Praying Hands are two memorials of the zinc miner's labors.
- Make circle route through park to south side of pit and return to Jct: Hwy. D). Head north on Main St.
- 15.65 Jct: Main St. (Hwy. D) and Daugherty St., turn right and head east on Daugherty St.
- 16.10 Mo-Pac RR crosses Daugherty St. Sunset Mine artesian flow area just east of railroad crossing.
- 16.20 STOP 4: SUNSET MINE. Several open shafts in this area have artesian flow of mine water except in extremely dry periods. The water enters Mineral Branch, a "miners canal", which winds its way through the mining fields and then enters Center Creek. The mineralized water turns reddish-brown after reaching the surface. The normal flow is about 2 cubic feet/second (900 gallons/minute).
- Turn around, head west on Daugherty St.
- 16.45 Jct: Daugherty St. and Main St. (Hwy. D). Turn right and head north on Main St.
- 17.15 Independent Gravel Co., Webb City Plant entrance on right. This is another chat processing plant.
- 18.05 Jct: Main St. (Hwy D) and paved road, turn left and head west on paved road.
- 18.20 Yellow Dog American Beauty Mine. These "high grade ore" mines were entered via concrete-walled incline shafts, angled about 40 degrees from the surface.
- 18.45 Red Dog Mine (south workings), open shaft adjacent to road, south side.
- 18.65 Jct: Paved road and Madison St. (unmarked). Turn right and head north on Madison St.
- 19.40 Madison St. crosses Center Creek.
- Many flooded mine openings in the lowlands adjacent to Center Creek. When these overflow in wet weather, high concentrations of zinc and sulfate contaminate Center Creek and have caused occasional fish kills.
- 19.65 Veer right (no bears on this trip).

- 19.95 Jct: Madison St. and Hwy. MM. Town of Oronogo. Turn left and head west on Hwy. MM.

The town of Oronogo was called Minersville in the early days, but no one knows just how the present name came to be adopted. It most probably is a distorted Spanish name. But the following account credited to a Johnny Shrader of Arkansas who heard it in Joplin about 1900, describes a very colorful origin, as reported below:

"One time there was a bunch of Pukes lived over by Joplin, at a camp knowed as Minersville. The boys didn'n have nothing but picks and shovels in them days and maybe a windlass with a bucket. They just gophered around in prospect holes, because there wasn't no powder to speak of. Whenever they hit hard rock they would quit, and dig a new hole somewhere else. What they dug up was mostly white-looking ore that they called dry-bone or turkey-fat. There was lead in the stuff, though, and you could trade it for groceries in the store."

"Old lady Bradley was running the boarding house at Minersville then, and she had a pretty girl named Myrtle to wait on the table. Them overall boys was always a-following Myrtle around, but she never done no screwing unless they paid her first. A fellow named Taylor come down with the horn colic one night and he didnt have the two dollars. Taylor kept hollering how he'd have the money come Saturday night, but Myrtle just laughed, because she'd heard that song before. "fetch me a gunnysack full of turkey-fat," she says, "and we'll talk business." Taylor begun to cry like a baby, but he didn't have no turkey-fat neither. "bawling won't buy nothing at the store," says Myrtle. "It's ore, or no go!"

"The walls in that boarding-house was just thin slabs without no plaster. Everybody in the house could hear what Myrtle told Taylor, and them prospectors just laughed theirself sick. It was kind of a joke in all the saloons, and finally they held a meeting to change the name of the camp. Minersville don't sound very good anyhow, but ore-or-no-go is kind of high toned. It all happened pretty nearly 80 year ago, but the name stuck. You can see Oronogo painted right on the post office window, any time you feel like driving up Main St."

- 20.00 Turn right to stay on Hwy. MM. Head north.

20.20 STOP 5. ORONOGO CIRCLE MINE.

This renowned pit is 800 feet in diameter and nearly 300 feet in depth. It is a large filled-sink structure in which the Pennsylvanian shales were present to a thickness of 150 feet. The bottom level of the circle is the sheet ground horizon of the Grand Falls Formation. The walls of the pit contain representatives of the Chester, Warsaw, Keokuk-Burlington Formations, which overlie the Grand Falls Formation. At this locality, all of the beds of the Mississippian limestone consisted of massive breccias containing ore.

This filled-sink deposit produced \$30 million worth of zinc and lead ores and was mined by 20 different companies from 1854-1966.

The Oronogo pit is used as a commercial recreational diving lake with instructors and diving equipment rentals. Five drowning deaths have been reported since the pit filled with water in 1945.

- 20.40 Return to previous Hwy. MM intersection. Turn left and head east on Hwy. MM.
- 20.45 Jct: Hwy MM and Madison St., turn right and head south on Madison St.
- 21.75 Veer right.
- 23.80 Jct: Madison St. and Hwy. 171. Turn right and head west on Hwy. 171.
- 25.80 Jct: Hwy. 171 and Hwy. 43. Turn left and head south on Hwy. 43.
- 26.80 Jct: Hwy. 43 and Fountain Rd. Turn right and head west on Fountain Rd.
- 28.80 Jct: Fountain Rd. and paved road. Turn left and head south on paved road.
- 29.95 Jct. paved roads. Turn right and continue south across Turkey Creek.
- 30.20 Leadville hollow on left. Site of initial ore discovery. Local history credits William Tingle and his nephew David Campbell with making the District's earliest lead discovery here adjacent to Turkey Creek.

William Tingle lived on Turkey creek prior to 1850 near the mouth of present day Leadville Hollow. At that time, Mr. Tingle had no title to the land on which he lived. His curiosity was aroused by the shallow depressions found along the creek bottoms which were apparently were not the result of uprooted trees or burrowing animals. In 1849 or 1850, he was visited by a nephew, David Campbell, who reportedly had mined lead (one story says copper) in Southeast Missouri and was therefore knowledgeable of lead occurrences and its mining. Mr. Tingle interested Campbell in these depressions and furnished him with room and board and tools to investigate them. Mr. Campbell is reported to have found galena ore and with Mr. Tingle's help started mining.

- 31.00 Jct: Paved road and Hwy. P (Schifferdecker Ave.). Continue south on Hwy. P.
- 31.35 Jct: Hwy. P and West Perkins St. Turn left and head east on West Perkins St.
- 32.20 Jct: West Perkins St. and McCoy Ave. Turn right on McCoy Ave. and head south.
- 32.35 Jct: McCoy Ave. and B St. (unmarked) just past Glover St. Turn right and head south on B St.

32.40 STOP 6--BULL FROG Pit Entrance on right.

This subsided area is an excellent example of a hazardous site within the city of Joplin. This hole, which measures 350 feet long and 250 feet wide (depth unknown), is literally in the backyard of some residences. It is also a good collecting spot for sphalerite, galena, calcite, dolomite and bitumen.

- 32.60 Leave Bull Frog Pit Area. Turn left off of gravel road. Return to McCoy Ave. via A St.
- 33.05 Jct: McCoy Ave. and A St. Turn right and head south on McCoy St.
- 33.20 Jct: McCoy Ave. and 2nd St. Turn left and head east on 2nd St.
- 33.30 Jct: 2nd St. and Maiden Ln. Turn right and head south on Maiden Ln.
- 33.40 Jct: Maiden Ln. and 4th St. The bowling alley on the left (northeast corner of intersection) utilizes underground mine waters from the Prairie Chicken Mine. The water is pumped through the building's air conditioning system and provides an economical heat transfer via the cool underground reservoir.
- 34.40 Jct: 4th St. and Schifferdecker Ave. Continue west into Schifferdecker Park.

STOP 7: Tri-State Mineral Museum. The museum, established in 1930 and owned and operated by the city of Joplin was rebuilt and dedicated in 1973. Its purpose is to tell the story of the local zinc-lead mining industry that resulted in the founding of Joplin and many surrounding communities. The outstanding exhibits cover all aspects of mining, milling, and smelting, the uses of lead and zinc, and the industrial history of the district.

A collection of mining and milling machinery is displayed just west of the museum in a fenced enclosure. Many of the machines were developed and manufactured in the district to meet the needs for high tonnage production from hard and abrasive host rock. Locally manufactured mine hoists, rock crushers, grinding rolls and mineral jigs have been used around the world.

Featured in the exhibit are mine hoists, rock drills, ore tubs, mine pumps, rock crushers, grinding rolls, blacksmith equipment, mine-mill stoves, and a replica hand jig. Among the hoists are a belt driven paper-friction hoist (about 1880), steam powered geared hoists (1890-1910), and a two cylinder steam powered First Motion Hoist (about 1910). The rock drills include steam powered piston drills used about 1890, and some of the early air-hammer drills for wet drilling, introduced about 1914. A walking beam pump for surface installation, and triplex pumps used underground are on exhibit.

Schifferdecker Park also contains the Dorothea B. Historical Museum.

ALTERNATE---Turn left and head south on Schifferdecker Ave.

- 36.70 Jct: Schifferdecker Ave. and 32nd St. Turn left and head east on 32nd St.
- 37.60 Jct: 32nd St. and McClelland St. Turn left and head north on McClelland St. Note large asphalt patch in center of roadway. This is a repaired shaft collapse. This site overlies pre-1900 mine workings of the Empire Zinc Co. A 20-foot diameter collapse hole was filled and repaired by the City of Joplin in the late 1970's.
- 37.90 McClelland Medical Building entrance on right. Large asphalt patches indicates collapsed area in the parking lot southeast of the building. A 60-foot deep hole opened on June 1, 1982. The collapse, measuring 10 X 25 feet at the surface, soon filled with water to within 20 feet of the surface. Backfilling and concrete/asphalt patching has temporarily safeguarded this site. The area is underlain by shallow underground workings known as the Eagle Mines.
- 38.15 Jct: McClelland St. and Gabby Street Blvd. (26th St.). Turn right and head east on Gabby Street Blvd.
- 38.45 Jct: Gabby Street Blvd. and Picher St. Turn right and head south on Picher St.
- 38.60 Ozark Health Center entrance on right. Three collapse areas, indicated by asphalt patches, in the parking lot. The largest collapse occurred at this site during November, 1981, when a 15-foot diameter hole opened in the asphalt parking lot. This hole was 30 feet deep and a sewer line was exposed near the base of the opening. This area is underlain by the Anne Baxter Mine which was worked at depths of from 55 to 75 feet.
- 38.75 Return to Gabby Street Blvd./Picher St. intersection. Turn right and head south on Main St.
- 39.40 Jct: Gabby St. Blvd. and main St. (Hwy. 43). Turn right and head south on Main St.
- 39.90 Jct: main St. and 32nd St. Turn left and head east on 32nd St.
- 41.30 Sunnyvale Subdivision on right. The Sunnyvale subdivision area has undergone nearly complete removal of all traces of past mining. Several shafts, many prospect holes, and one large open pit were filled during the initial land-leveling work. This subdivision is typical of the reclamation carried out in the older mining areas within the Joplin Metropolitan area.
- 41.90 Jct: 32nd St. and Rangeline Dr. (Hwy. 71). Turn right and head south on Rangeline Dr.
- 42.25 Holiday Inn entrance on left.

ROAD LOG FOR SATURDAY MORNING FIELD TRIP

September 27, 1986

Waldemar M. Dressel

307 Christy Drive
Rolla, Missouri 65401

MILEAGE

CUM.

DIFF.

- 0.0 Leave parking lot of Holiday Inn, turn right on to Rangeline. Get
0.35 into left lane for left turn at 32nd Street.
- 0.35 Left turn on to 32nd St. Follow 32nd St. for approximately 4 miles.
2.0
- 2.35 Main Street. Continue west on 32nd St.
1.0
- 3.35 Maiden Lane. Continue west on 32nd St. The area along both sides of
1.0 Maiden Lane was heavily mined. This area has been reclaimed for use as
residential land sites.
- 4.35 Schifferdecker Ave. Turn right (head north).
1.0
- 5.35 20th St. Turn left on to 20th St.
1.0
- 6.35 This was a heavily mined area for the next mile. Most evidence has
1.0 been removed.
- 7.35 You are now passing through the heart of downtown Central City, a once
1.65 prosperous mining town.
- 9.0 Doan Feed Company. Follow the road to the right just past the mill.
.25 This is the Kansas State line. The abandoned "Old Rock Distillery" is
just west of the state line.
- 9.25 Turn left. Note the abandoned mine lands ahead. This is the eastern
.40 edge of the "Galena Camp".
- 9.65 Highway 66, dual lane crossing. Cross with care and turn left.
.20
- 9.85 Turn right on Bellevue Street, just past Halls Food Mart (Texaco
.35 Station). Bellevue Street consists of short street with stop signs at
every intersection. It then fades into a trail. Keep right along the
trail.

- 10.20 STOP No. 1. Southside 80 Mining Tract - T34S-R25E - SW 1/4 Sec. 14
 .10 -- CAUTION -- There are over 60 open mine shafts and 50 subsidence features in this quarter section. Watch your step. We can probably get you out of most of the collapsed areas, but if you fall into one of these open shafts it could ruin our whole (hole) day.
 Mining in this area was in the lower Warsaw or upper Burlington. It was one of the richest areas in the Tri-State District. The mining was done on individual 200 feet square mining lots or leases by small crews consisting usually of only two men using hand tools and a simple man or horse-powered hoisting device. It took two men working all day to drill a seven foot hole, with one man holding the steel while the other hit with a hammer in the morning and then reversing the procedure in the afternoon.
- Shafts were sunk until traces of ore were found and then drifting out to reach ore grade material. If an ore body was found, the miners began stopping to recover the ore. Pillars were left during mining but were generally heavily robbed or totally removed before abandoning the workings. Additional shafts were sunk if ventilation was too bad or if the operators owned the lease on the adjoining mining lot. Lot lines were surveyed on the surface but underground surveys were seldom run.
- Some idea of the size of the worked out stopes can be visualized from the size of the subsidence craters now existing. Roof support was generally better at the base of the shafts so that the open shafts are sometimes the only thing standing between the subsidence pits.
- Note the rock line water way in the low area to the north. This was part of the mine water drainage system to remove the waters pumped.
- 10.30 Continue north, cross the railroad and turn left. The barren hillside
 .30 ahead probably reflects the denuding of vegetation caused by sulfur dioxide emissions from the now abandoned zinc smelter.
- 10.60 Turn left onto Old Highway 66. The Eagle-Picher smelter which was
 .50 dismantled in 1983 was just north of the highway. As we proceed west along this road a good view of the abandoned mines can be seen on the left.
- 11.1 Railroad overpass. Good view of the abandoned mine area referred to
 .20 locally as "hell's half acre".
- 11.3 Stop sign. This is Kansas Highway 27 N or Galena's Main Street.
 .30 Continue straight across Main Street onto Front Street which turns to the left on Wall Street.
- /

- 11.6 STOP 2 - This is the site of the Bureau of Mines shaft plugging demonstration. CAUTION - There are still some open mine shafts lurking in the weeds and bushes. There is one just a few feet off of Wall Street at Front St. Another about 25 feet north of Front St.

In this area just west of Wall Street between Front and 2nd Streets the Bureau of Mines installed two reinforced concrete caps and 11 inverted pyramid shaped plugs, and backfilled one shaft. The subsequent failure of the backfilled shaft was not anticipated, but did point out the need for more careful selection of backfilling material or methods on future backfilling operations.

Elevations have been run periodically on the shaft closure monuments. To date there has been no apparent subsidence of the plugs. The large water-filled open pits in the valley north of the demonstration site are abandoned open pit mines, rather than subsidence pits.

- .20 Proceed south on Wall Street.
- 11.8 Stop sign. Turn right onto Highway 66. Galena Municipal Building is on the right. The Galena Museum in the old railroad station has some interesting exhibits.
- .30 Move toward the center lane because a left turn will be coming up very soon.
- The Kansas Highway Department bridged over some mine workings in this location when the new highway was constructed. The two caps built by the Bureau of Mines on the demonstration site were essentially the same
- .20 as these bridges.
- 12.25 Turn left. Drive through more abandoned mine sites. The City of Galena has been attempting to limit dumping of trash in this area.
- .90 Habits are difficult to alter.
- 13.15 STOP 3. This stop shows much the same problems that existed in the Southside 80 Stop earlier today.
- .10
- 13.25 Turn right onto paved road. The Galena field continues for another mile to the south and to the west of this point.

At the edge of the field the formations grade into unaltered Mississippian lime bar devoid of mineralization. No ore bodies of any consequence have been discovered between the Galena field and the Baxter Springs deposits, a distance of about 5 miles.

- 2.3 There were some mines completed in the Reed Springs formation along Shoal Creek. One mine located about 2 miles south of this road was the deepest mine in the district, stratigraphically, even though it was only 125 feet deep. The mine shaft collared below the normal sheet ground.
- 15.55 Turn left at T intersection.
- .20

- 15.75 Curve to right.
.40
- 16.15 Curve to left. Broad Spring River Valley.
.2
- 16.35 Bridge across the Shoal Creek arm of the Spring River Lake. Town of
.10 Lowell. This was once a favorite spot for summer homes for the
well-to-do from Joplin, Kansas City, and Pittsburg, Kansas.
- 16.45 Intersection. Follow highway signs.
.25
- 16.70 Left turn.
.15
- 16.85 Right turn.
1.45
- 18.30 Stop sign. Highway 166, turn right.
1.45
- 19.75 Spring River bridge.
.80
- 20.55 Turn left at stop light onto Highway 66.
1.0
- 21.55 Left turn at bend in Highway before the McDonald Arches. Drive between
.2 King Louie and McDonald's.
- 21.75 Gravel Road. Proceed south.
.5
- 22.25 Turn right. This is the Oklahoma-Kansas State line road. There is a
0.2 bend in the road ahead around the edge of a mine collapse.
- 22.45 STOP 4. Wade property. There are a number of collapsed shafts on the
north side of the road. Surface water from a large drainage area
drains into these openings. The pits might be a combination of both
subsidence and shaft surface collapse. Note that there is little
similarity between the post mining conditions here as compared
0.1 to those existing in the Galena area.
- 22.55 Stop sign. This is Highway 66. Proceed with caution across Highway 66
and continue along the State Line Road. The large chat piles which can
be seen ahead give one an idea about the size of the mines in this
area. These chat piles are being utilized for railroad ballast, road
material, fill and other uses and these piles could be completely gone
in a few more years. Luza estimated in 1983 that there were
approximately 45 million cubic yards of chat remaining in the major
1.65 piles in Oklahoma.
- 24.2 Turn left
.55

- 24.75 STOP 5. Hockerville Baptist Church. Subsidence pit behind the church. T29N,R23E, Sec. 14, NE1/4. This is a stabilized circular subsidence collapse approximately 200 feet in diameter. This subsidence developed prior to 1939. Note that this feature has more or less stabilized over the years. There is usually water in the bottom of this pit. Trees
.25 are well established in this pit.
- 25.0 Stop 6. Lucky Jenny Mine straight ahead. The Lucky Jenny collapse is about 160 X 140 feet with a water level during the wet season about 40 feet from the surface. From air photos it has been determined that this subsidence occurred between 1964 and 1972. The side walls of this pit have not yet stabilized. Note the extensive shale section and coal seams in the shale section.
- .15 Turn right
- 25.15 Turn right
.10
- 25.25 STOP 6. Two more subsidence features. One is well stabilized and full of junk. The other is poorly stabilized and continues to grow, particularly during wet weather. This area subsided between 1964 and
0.2 1972. Mine workings here were between 125 ft. and 180 ft. deep.
- 25.45 Turn left on State Line Road.
2.60
- 28.05 Stop sign at U.S. Hwy. 69. Picher, Oklahoma. Turn right on Hwy. 69.
.50
- 28.55 STOP 7. Barr Mine on right. There is an open shaft along side of the subsided roadway. Just north of the old mill roadway is a 150 X 300 ft.; 60 ft. deep pit developed between 1950 and 1973. This pit continues to expand. The Barr mine was over 250 ft. deep and had mined out rooms which were in excess of 90 feet tall. The Barr Mine extends under Hwy. 69.
- The Miami trough (syncline) with a NE-SW axis passes through this general area. The Bendelari trough (monocline) which runs NW-SE intersects the Miami trough about a mile SW of the Barr
0.7 mine.
- 29.25 Left turn onto gravel road.
1.25
- 30.50 STOP 8. Muncie Pit, Tar Creek. The Muncie subsidence pit intercepted the flow of Tar Creek. The surface elevation at this location is about 850 feet. The water level in the pit was about 800 feet. Tar Creek waters flowing into this pit displaced mine water in the underground workings and flowed from the mine from drill holes and open shafts
0.5 along Tar Creek at elevations about 800 feet.

- 31.0 STOP 9. Big John Mine on the south side of the road. At this point a tributary of Tar Creek was intercepted by an open mine shaft. Large flows of water entered the shaft during wet weather. The elevation here is approximately 850 feet, 50 feet higher than the point of discharge of mine waters about four miles south of here.
.25
- 31.25 Turn left
1.0
- 32.25 Turn left. This will lead us through the town of Treece, an important mining town during the glory days of the Picher field.
2.0
- 34.25 Turn right on Highway 69.
0.2
- 34.45 Oklahoma-Kansas State Line. Continue south through Picher, past the large tailing pile and used auto storage area.
1.5
- 35.95 Follow paved road branching off to the right and head for Cardin.
0.5 There are mined out workings with high backs located under this road.
- 36.45 Tar Creek. Tar Spring is located 600 feet north of the road. It reportedly was a spring with medicinal or healing properties. It was a source of tarry material for the Indians.

Tar evidently played a big part in the deposition of the zinc deposits, or the deposition of the sulfides had an important bearing on the formation of the tars.
0.1
- 36.55 Cardin. The American Zinc Co. Offices were located in the gray building on the right.
0.8
- 37.35 Keep straight ahead, even though the main road bends to the left. Eagle Picher Offices were located on the right. The building is now used by Weseda, Ltd., makers of off-the-road mining equipment.
0.2
- 37.85 STOP 10. On the right side of the road there are 18 subsidence craters located on a 40 acre tract. Three of these subsidences developed prior to 1939, three between 1939 and 1952, none between 1952 and 1964, one between 1964 and 1972, and twelve between 1972 and 1979. The pumps ceased pumping about 1970 and the mines were filling with water during the period of the largest number of incidences. There might be some relationship between the two.
0.2
- 38.05 Turn left at old Power Plant which is now occupied by Weseda, Ltd.
0.3
- 38.35 Blue Goose Mine tailing pile. A 450 X 320 foot elliptical collapse occurred within this chat pile between 1952 and 1964. It has enlarged since 1980. This makes an exciting playground for off-the-road vehicle operators.

One of the most recent documented subsidences is in the field just a quarter of a mile to the right (west) of this point on the "Goodeagle" lease.
1.0

- 39.35 Make a hard left. Site of Eagle Picher's Central Mill.
0.3
- 39.65 Turn right. This road takes you between two large abandoned flotation
tailings ponds. These areas are healing, but are still quite dusty
1.0 during dry and windy weather.
- 40.65 STOP 11. TAR CREEK (Century-Douthat). This is the site that has made
the news for several years. Geologists from Eagle Picher and the US
Geological Survey had predicted when the mine would be filled with
approximately 39 billion gallons of water. Because of an unusually wet
year the mines actually filled and began to overflow about 6 months
earlier than predicted.
- The iron-bearing waters began to flow into Tar Creek and the general
population realized that what had been predicted was now fact. After
several studies a program was developed by the U.S. Environmental
Agency to help control the amount of metal containing water flowing
from the mine openings.
- 1.0 The flow fluctuates with rainfall, but there was a good flow into
Lytle-Tar Creek on the 1st of August, 1986.
- 41.65 Highway 69. Turn left.
0.7
- 42.35 Open shaft on the right is a good place to collect Ruby Jack specimens.
1.6
- 43.9 Picher, Oklahoma.
0.2
- 44.1 Stop sign.
1.0
- 45.1 Kansas State Line.
2.7
- 47.8 Intersection of Hwys. 66 and 69. Turn right on Hwy. 66
2.2
- 50.0 Water Tower on the right is site of Swalley Mine-inclined shaft and
2.1 water treatment plant.
- 52.1 Baxter Springs.
0.8
- 52.9 Stop light. Turn left on Hwy. 66.
0.6
- 53.5 Baxter Springs High School on the right.
3.7
- 57.2 Riverton.
0.2

- 57.4 Riverton Power Plant on right.
0.1
- 57.5 Spring River Inn---Turn left. Eat and return to Hwy. 66. Turn left
3.1 and head for Joplin.
- 60.6 Galena.
0.2
- 60.8 Stop light in Galena.
0.8
- 61.6 Turn right
0.4
- 62.0 Missouri State Line, Turn right.
0.2
- 62.2 20th Street, keep left. Continue east on 20th to Rangeline.
8.0
- 70.2 Turn right on Rangeline.
1.4
- 71.6 Holiday Inn, Turn left.
- This is the end of another memorable AMG field trip.

A BRIEF DESCRIPTION OF THE HISTORICAL, ORE PRODUCTION, MINE PUMPING, AND
PROSPECTING ASPECTS OF THE TRI-STATE ZINC-LEAD DISTRICT OF MISSOURI,
KANSAS, AND OKLAHOMA

Daniel R. Stewart

Route 1, Box 158
Webb City, Missouri 64870

GENERAL STATEMENT

The Tri-State district of Missouri, Kansas, and Oklahoma was one of the foremost mining areas of the world, having produced, during the years 1850 through 1950, 50 percent of the zinc, and 10 percent of the lead consumed in the United States. After some 133 years of almost continuous production from more than 4,000 mines, it is now dead, with all of the mines being flooded with water. During its life it produced some 23,000,000 tons of zinc concentrates, and almost 4,000,000 tons of lead concentrates, from a total of nearly 500,000,000 tons of mined ore.

The ore discoveries, dating back to 1838, were responsible for the settlement and establishment of the towns and cities of the area, and provided a large manufacturing base for mining machinery and explosives that were formerly shipped to other parts of the country. During the peak years of production more than 11,000 underground miners were employed, with approximately three times that number being engaged in supporting industries. Although mining in the district gradually ceased during the years 1957 through 1970, the economic impact of this loss is just now beginning to stabilize with only minor adjustments in population. The slack in employment is being absorbed by expansions in the local chemical, light manufacturing, machine shop, and transportation industries.

The geology of the district as a whole is a relatively simple sequence of Mississippian cherty limestones, that becomes exceedingly complex in those areas of intense deformation where limestone dissolution has been active. The ore bodies themselves are also complex, being found as scattered masses in areas of localized rock alteration, where they can occur as single deposits, or as clusters covering several miles. For this paper the subjects of mine geology and ore deposition have been omitted for a more comprehensive review at a later date.

With the ore deposits occurring at relatively shallow depths in an area of good transportation, abundant labor, and assured markets, a mine could be found, developed, and operated for a small capital investment. As a general rule the shallow mines were of limited size, averaging less than 200,000 tons, and became depleted after five to ten years of operation. As a result of these operating conditions the district became a mecca for small mining organizations, that erected mine and mill plants that could be easily moved from one location to another. Because of the low grade ores being mined, efficiency was paramount, with the operators developing mining and milling equipment that yielded some of the lowest operating costs in the country.

From the foregoing it might be assumed that the district was entirely operated by many hundreds of small mining outfits, but it also had its share of captive mines operated by the major smelting companies of the country. These included Asarco Inc., American Metals Co., DuPont Chemical Co., National Lead Co., St. Joseph Lead Co., U.S. Mining, Smelting, and Refining Co., U.S. Steel Co., and United Zinc Co. In addition a number of large mining and smelting companies sprang from their early roots in the district. These included American Zinc, Lead and Smelting Co., Athletic Mining and Smelting Co., and Eagle-Picher Co.

The following discussion is a brief review of the historical, production, mine pumping, and prospecting aspects of the district.

MINING HISTORY

Probably the first mention of possible ore deposits in southwestern Missouri was that by Moses Austin (1804), a mine operator from southeastern Missouri, in his report to President Thomas Jefferson on mining in the Louisiana Territory. In this report he states that "valuable Lead mines have likewise been discovered about 200 miles up the river Meramec." The first documented ore discovery was reported by Henry R. Schoolcraft (1821), when he noted occurrences of galena and sphalerite in outcrops along the upper reaches of the James River in what is now Christian County. He states that during the early part of 1819 he built a crude log furnace and smelted a small quantity of lead for bullets. There were undoubtedly other unreported discoveries made by the early frontiersmen, but it was not until 1838, 19 years later, that the first commercial mining-smelting operation was begun by Joseph W. McClurg, later Governor of Missouri. McClurg together with his partner, a Mr. Murphy, erected a log furnace and mined a small ore deposit located near "Devils Den" on Panther Creek in Webster County. This operation lasted for about one year, producing metallic lead for local consumption.

Following other ill-fated mining-smelting ventures in Greene and Christian Counties, the more prolific ore deposits of Jasper and Newton Counties were discovered in about 1848. These later discoveries resulted in mining camps being established during the pre-Civil War period on Turkey Creek and Center Creek in Jasper County, and at Spurgeon, Moseley, and Granby in Newton County. As ore production increased the primitive log furnaces were soon replaced with centrally located Scotch-hearth smelters located at Granby and Moseley in Newton County, and on Center Creek in Jasper County. During this period the shipments of the metallic lead produced to the St. Louis and other eastern markets presented quite a problem, requiring wagon hauls of up to 250 miles. The nearest shipping points were such river ports as Booneville and Jefferson City on the Missouri River; Osceola, Lynn Creek, and Bagnell on the Osage River; Ft. Smith on the Arkansas River; and the nearest railheads at Tipton and Moselle.

With southwestern Missouri being one of the early battlegrounds of the Civil War, all mining was halted in 1861 with most of the residents fleeing the area to Texas and Kansas. Following the cessation of hostilities in 1865, many of the early miners returned to the district, with mining being resumed in the Granby, Turkey Creek, and Center Creek areas. During the next four years, to 1869, surface prospecting was expanded with new mining camps being established in the Sherwood-Zincite-Klondike; Webb City-Carterville; Duenweg-Porto Rico;

and Carthage areas. In addition limited mine production was reported from fringe areas lying in Hickory; Taney; Wright; Christian; Greene; and Ozark Counties. For the period from the beginning of mining to 1869 all mine shipments from the district were in the form of metallic lead locally smelted on primitive log furnaces and crude Scotch-hearths. Total production averaged less than 1,000 tons per annum.

Although the zinc minerals of the district had been reported as early as 1821, and were described in detail by Prof. G. C. Swallow (1854) in his report on the Mines of Southwestern Missouri, the lack of a ready market forced the miners to cast the zinc ores aside as rubbish. The first recorded shipment of zinc concentrates from the district was a bulk sample from Granby of zinc silicate (calamine), which was sent in 1869 to a zinc smelter in St. Louis, Mo. The net value of the concentrates, after freight and treatment, ranged from three to five dollars per ton.

For practical purposes the mining boom period of the district began in 1870. This was the year that the railroad from St. Louis reached Granby, Neosho, and Seneca; and the railroad from Kansas City reached Baxter Springs in Kansas. It was also the year of discovery for the fabulously rich shallow ore deposits along Joplin Creek at Joplin. With both of these events in place, the population exploded with Joplin reaching 10,000 people by 1877. Mine production soared, reaching an average output of concentrates of about 26,000 annual tons. With railroad connections established to the zinc smelters in the St. Louis and northern Illinois areas, zinc production expanded rapidly, and by the end of the decade exceeded that of lead. To treat the lead ores the district boasted a total of 12 modern lead smelters, 11 of which were in Joplin. To provide a near-by market for the zinc, coal-fired zinc smelters were constructed at Weir City, Kansas, in 1873, and at Pittsburg, Kansas, in 1878. In 1879 ground was broken for a coal-fired zinc smelter at Joplin to treat 6,000 annual tons of concentrates. Also during the decade new mining camps were opened in the Sarcovie-Reeds; Ash Grove-Everton; Fairview-McDowell; and Galena, Kansas areas.

The next decade from 1880 to 1889 was one of great expansion, with steam power being widely used for mine pumping, hoisting, air compressing, and powering the crude concentrating plants. The production of lead and zinc concentrates increased more than 800 percent over the preceding decade, rising to an annual average of 114,000 tons. The new zinc smelter of the Joplin Zinc Co. was completed in 1881, and with zinc production increasing by leaps and bounds, other coal-fired zinc smelters were constructed at Rich Hill and Nevada in Missouri; and at Pittsburg, Scammon, and Girard in Kansas. As prospecting continued new mining camps were discovered in the Aurora, Alba-Neck City, Stotts City, and Wentworth areas of Missouri.

The period from 1890 to 1910, or the next 20 years, was marked by a great expansion of mining activity, brought about by the development of the large tonnage sheet-ground mines in the Duenweg, Porto Rico, Prosperity, Carterville, Webb City, Oronogo, and west Joplin areas. These ore deposits were typically low grade, averaging less than 2 percent as metallic zinc and lead, but had continuity over large areas, and readily lent themselves to volume mining. Through the ingenuity of the mine operators, large capital investments, and the use of advanced technology in both mining and milling, more than 200 sheet-ground mines were operated profitably. Crane reported that there were 99 ore processing mills in the Galena District in 1899 (Crane, W.R., Methods of

Prospecting, Mining and Milling in Kansas Lead and Zinc District, Kansas Geological Survey, Volume VIII, 1901). Mine production during these 20 years soared to an average annual output of about 236,000 tons of zinc and lead concentrates, more than double the previous decade. The discovery of large quantities of natural gas in southeastern Kansas and northeastern Oklahoma during the early 1890's brought about the demise of the coal-fired zinc smelters. By 1894 most of the coal-fired smelters had been replaced by 18 gas-fired plants, of which 10 were located in Kansas, 6 in Oklahoma, and 2 in Arkansas. The new mining camps opened during this period included the Carl Junction and Diamond areas in Missouri; the Badger-Peacock and Lawton-Waco areas in Kansas; and the Peoria, Quapaw, Lincolnville, and Commerce areas in Oklahoma.

The 1910 to 1919 decade was of great importance to the mining district with the industry not only enjoying the increased prices for lead and zinc caused by World War I, but it was also the time of the major ore discoveries at Picher, Oklahoma in 1914. With the combination of satisfactory metal prices, and the large mines coming on stream in the Picher area, total mine production climbed to an annual average of about 353,000 concentrate tons. Also during this period new areas of zinc-lead mines were discovered in the Stark City and Waco subdistricts of Missouri, and in the Baxter Springs-Treece area of Kansas.

The 1920 to 1929 period was the "golden years" of the district, with the new mines in the Picher field reaching their maximum development. In order to maintain their position as important ore producers, most of the larger mining companies in the Missouri "sheet-ground" areas, acquired land holdings in the Picher and Baxter Springs-Treece fields, and moved their mining and milling equipment to this new area of activity. This exodus marked the end of the large-scale "sheet-ground" mining in Missouri, with the remaining mining activity being limited to the smaller upperground ore deposits that contained richer ore. The peak production of the district was reached in 1926, when a total of 956,319 concentrate tons were produced. The average annual yield for the decade was about 629,000 tons of concentrates. Although exploratory prospecting was continued at an active pace, the only new ore discoveries were those made in 1922 located in the Playter-Crestline areas in Kansas.

The 1930 to 1939 decade included the period of the Great Depression, during which the prices for zinc concentrates tumbled from a high of \$78.81 per ton in 1921, to a low of \$18.25 per ton in 1932. The average price for lead concentrates also fell from a high of \$117.21 in 1925 to a low of \$35.56 per ton in 1932. The sharp collapse of the metal prices forced most of the mines of the district to cease production, with only the larger mining companies continuing limited operations to help cover mine pumping costs. Total concentrate production for the decade fell approximately one half to an annual average of about 337,000 tons. During the years following 1932 the metal values slowly recovered, and by 1939 had reached average prices of \$34.37 per concentrate ton for zinc, and \$58.66 per concentrate ton for lead. With profit margins severely reduced, prospect drilling was curtailed and confined to the fringe areas of existing mines.

The operating period from 1940 to 1949 was one of many ups and downs, with the mining industry being subjected to the governmental controls associated with World War II. In 1942, as part of the war effort, the prices for lead and zinc were frozen, with the values for concentrates being determined by a complicated formula based on mine recovery percentages. The pricing formula

for lead and zinc ores was administrated by the Metals Reserve Co., a governmental agency, and was known as the "Premium Price Plan". Under this program the mining of lower grade ores was encouraged, with many marginal ore deposits being reopened and worked. When the Premium Price Plan was finally terminated in 1947, most of the lower grade mines, including almost all of the Missouri production, were permanently closed. Following the lifting of the governmental pricing controls, the market prices for zinc and lead concentrates never fully recovered to satisfactory profit margins. Limited mining was continued by the larger companies in the Oklahoma and Kansas portions of the district where higher grade ores could be extracted. Mine production for the decade was only slightly above the preceding period of depression years, and averaged approximately 350,000 tons of combined concentrates per year. During the latter part of the decade some of the larger mining companies were granted prospect drilling loans from the Defense Minerals Exploration Agency, whereby the federal government financed one half of the exploration costs to be repaid from future production. The few participation loans granted in this district yielded no worthwhile discoveries.

The 1950 to 1959 period marked the end of the major mining activities within the Tri-State district. Outside of a short upswing in metal prices during the Korean Conflict, metal prices continued to deteriorate with all of the major mining operations shutting-down in 1957. With the uses for zinc and lead beginning to wane, and with abundant supplies of these metals being available from abroad, the mining economics in the district was entering a phase of no return. Since the mining and milling equipment was in place at the time of the general shut-down, a limited production was continued by small groups of former employees, who mined the higher grade portions of the mines as independent operators. Although some mining was being conducted throughout the decade, the overall production declined to less than 100,000 tons of concentrates per year.

The period from 1960 through 1969 was one of continued declining production, with the final demise of a once great mining district occurring in 1970. In order to provide jobs for many of the unemployed miners, the U. S. Congress, in 1960, passed the "Small Producers Lead and Zinc Mining Stabilization Act", which granted a subsidy to small groups of miners that could qualify for the bonus. Under this program the small mining organizations would sublease portions of the existing mines from the former operators, rent the mining equipment already in place, and mill their ore production at the sublessor's concentrating plant on a toll basis. The economics of this arrangement between the larger mining companies and the small operators was not too satisfactory, and the program was phased-out during the years following 1965. Although some limited mining continued until the final demise in 1970, the production for the decade probably averaged less than 10,000 tons of concentrates per year.

The last major mining effort in the district was that by the Eagle-Picher Company during the latter part of the 1960's. This project contemplated the reopening and modernizing one of long abandoned sheet-ground mines in the Baxter Springs, Kansas, area, and equipping it for volume mining. After spending considerable money to dewater the property, sink a new inclined shaft, and install railroad connections for hauling the ore to the Central Mill at Picher, Oklahoma, the project was terminated when the mine water discharge failed to meet the quality standards set by State and Federal environmental organizations. This area had long been known to contain above normal acidic

water, but the acidity had increased from the oxidizing waters that had flooded the mine workings during the period of abandonment. Much time and effort was spent to improve the quality of the discharge water through the use of treatment ponds, but the expense to reach the desired standards proved to be prohibitive.

PRODUCTION

Mine production in the district was different from the other base metal mining centers of the country, in that the ore produced came from literally thousands of mining operations scattered over the 2,500 square miles that define the boundaries of the area. Within this area the ore deposits were not distributed in an uniform pattern, but occurred as erratically spaced groups, or clusters, that formed the mining camps, which later have been identified as "subdistricts". The Statistical Division of the U.S. Bureau of Mines recognized a total of 31 separate and distinct centers of mining operations. Of the various subdistricts some were comparatively small, producing less than 20,000 tons of ore, while others reached total ore production in excess of 180,000,000 tons.

Although the area is primarily known as a zinc producing district, only the associated lead ores, which were locally smelted, were produced during the first 32 years of its productive life. Zinc production began in about 1870, when railroad connections were completed to the zinc smelting locations in the northern Illinois and St. Louis areas. With zinc markets being firmly established, mining operations boomed, reaching their peak in 1926, when a total ore production of 15,716,400 tons was mined during that year. Following the peak year mine production slowly declined with all mining operation ceasing in 1970. Over the 133 year productive life of the district the ratio of zinc to lead averaged 6 to 1 in the form of concentrates produced, and 4 to 1 in the form of recoverable metal.

Complete mine production statistics for the district are only partially available, with accurate figures, covering both tons mined and concentrates produced, being recorded only for the years 1907 through the cessation of mining in 1970 by the U.S. Bureau of Mines, or for the last 64 years. Fortunately, partial production records of concentrates produced for the years 1850 through 1906, are available from various scattered sources. These include the early reports of the Missouri Geological Survey, the Missouri State Mine Inspector, and the U.S. Census Bureau; plus old newspaper files, railroad shipment records, and statistics gathered by the early ore buyers. For a compilation of the pre-1907 concentrate production figures, the district is deeply indebted to Mr. A. J. Martin, Supervising Statistician, U.S. Bureau of Mines, who made a careful study of the older records for his report, published as Information Circular, No. 7383, U.S. Bureau of Mines, November 1946.

In order to show the district's total production in terms of tons mined, as well as tons of concentrates produced, efforts have been made to reconstruct estimated mine tonnage figures for the 57 year period from 1850 through 1906, by each subdistrict, and by each State. For this exercise the 13 year period from 1838 to 1850 has been ignored from lack of information, and as being of minor importance. Although the resulting production figures for the district from 1850 through 1970 include both estimated and actual tonnage figures, they are believed to be reasonably accurate.

For the purpose of estimating the mine tonnages for the period these figures were not recorded, concentration ratios were used to convert the concentrate tonnages to tons of crude ore mined. Since most of the ore deposits of the district occur as open-spaced fillings in either layered or brecciated chert masses, the concentration ratios are fairly constant. By using calculated concentrations ratios from areas having complete production records, and by knowing the types of ore deposits in the older parts of the district, estimated mine tonnage figures can be reconstructed. As a general rule these ratios vary from a low of about 33 tons of ore to 1 ton of concentrates in layered chert deposits, to an average of 17 tons of ore to 1 ton of concentrates in the brecciated chert deposits. The average concentration ratio for the district as a whole is approximately 19 tons of ore to each ton of lead and zinc concentrates combined, or 5.371 percent as total concentrates produced, or 2.936 percent as total recoverable metal.

Table 1 shows the recoverable lead and zinc (as metals), operating periods, and estimated tons mined, by States, and for the district as a whole. The production figures for the short tons of recoverable lead and zinc (as metal) are the actual tonnages from the start of mining to the close of 1970, as reported by the U.S. Bureau of Mines. The table also shows the ratios between the tons of lead and zinc produced, expressed both in terms of recoverable metal, and in terms of concentrates sold. In addition, the average grades for the mined ore are shown as percentages of the recoverable metals, and also as percentages of the concentrates produced.

TABLE 1 - MINE PRODUCTION - BY STATES
TRI - STATE DISTRICT
 (For years 1850 to 1970 incl.)

<u>State</u>	<u>Operating Period</u>	<u>Est. Tons Mined (st)*</u>	<u>Recoverable Metal (st)</u>		<u>Ratio Zn/Pb</u>
			<u>Lead</u>	<u>Zinc</u>	
Missouri	1850-1957	196,000,000	885,390	3,618,930	4.1/1
Kansas	1876-1970	115,000,000	691,338	2,900,000	4.2/1
Oklahoma	1891-1970	187,000,000	1,306,679	5,219,998	4.0/1
<u>Totals (Metal)</u>		<u>498,000,000</u>	<u>2,883,407</u>	<u>11,738,928</u>	<u>4.1/1</u>
<u>Totals (Concentrates)</u>		<u>"</u>	<u>3,800,923</u>	<u>22,945,660</u>	<u>6.0/1</u>
Average Grade (% Metal)			0.579	2.357	
Average Grade (% Concentrates)			0.763	4.608	

(*) Figures rounded to nearest one million tons, and consist of estimated tonnages for 1850-1906 and 1946-1970 periods.

SUBDISTRICTS

Of the 31 subdistricts (mining camps) as recognized by the U.S. Bureau of Mines, 24 are in Missouri, 5 are in Kansas, and 2 are in Oklahoma. In order to show the distribution of mining in the district, estimated tonnages for the crude ore produced were calculated for each of the subdistricts. Table 2 shows the operating periods, and the estimated mine tonnages for the 21 subdistricts yielding in excess of one million tons. The results of this study show that the district was dominated by the huge output from the Picher-Commerce-Quapaw subdistrict, which yielded about 187,000,000 tons of ore, or 37½ percent of an estimated total production of 498,000,000 tons. Following in order of decreasing rank, are two subdistricts in the 50 to 100 million ton range; four in the 10 to 50 million ton range; five in the 5 to 10 million ton range; and nine in the 1 to 5 million ton range. It is of interest to note that 99 percent of the total production came from 21 subdistricts that yielded more than one million tons each. The remaining subdistricts, 10 in number, are all small mining camps located on the fringes of the district, and collectively produced less than 1 percent of the total output.

TABLE 2 - ESTIMATED MINE ORE TONNAGE
BY SUBDISTRICTS

Subdistrict	Operating Period	Est. Tons Mined (st)*
1. Picher-Commerce-Quapaw	1904-1970	187,000,000
2. Baxter Springs-Treece	1917-1970	83,000,000
3. Webb City-Carterville-Prosperity	1851-1957	79,000,000
4. Joplin	1850-1957	35,000,000
5. Galena	1876-1957	23,000,000
6. Duenweg-Porto Rico	1851-1957	20,000,000
7. Granby	1850-1947	13,000,000
8. Oronogo	1850-1947	9,000,000
9. Alba-Neck City	1886-1954	7,000,000
10. Aurora	1886-1957	7,000,000
11. Waco-Lawton (Kan.)	1911-1950	6,000,000
12. Waco (Mo.)	1918-1957	5,000,000
13. Zincite-Klondike-Smithfield	1850-1950	3,400,000
14. Spring City-Seneca-Spurgeon	1850-1950	3,300,000
15. Carthage	1854-1950	2,600,000
16. Mitchell-Sherwood-Thoms	1850-1950	2,500,000
17. Cave Springs-Central City	1850-1957	2,500,000
18. Carl Junction	1900-1947	1,500,000
19. Badger-Peacock	1904-1947	1,500,000
20. Wentworth	1889-1957	1,000,000
21. Crestline-Playter	1906-1950	1,000,000
<u>Total (plus one million ton subdistricts)</u>		<u>493,300,000</u>
<u>Total for other small subdistricts (ten)</u>		<u>4,700,000</u>
<u>GRAND TOTAL FOR DISTRICT</u>		<u>498,000,000</u>

(*) All estimated tonnage figures rounded

OXIDIZED ORE MINERALS

In addition to the major production of lead concentrates in the form of galena (lead sulfide), and zinc concentrates in the form of sphalerite (zinc sulfide), the district also produced important quantities of oxidized ore minerals of both lead and zinc. The oxidized ore minerals consisted of cerussite (lead carbonate), which was sold for its lead content; plus calamine (zinc silicate) and smithsonite (zinc carbonate), which were sold for their zinc content. Concentrates of these minerals were produced in those subdistricts where the ore deposits occurred above the ground water table. For the years 1898 through 1945, the U.S. Bureau of Mines reports production totaling 9,531 tons of lead carbonate, and 329,386 tons of combined zinc carbonate and zinc silicate. When considering the pre-1898 years, these figures would more than double, since most of the early mining was from the near surface ore deposits. Subdistricts that produced large tonnages of oxidized ore minerals, in order of decreasing rank, were; Granby, Aurora, Spring City-Seneca-Spurgeon, Duenweg-Porto Rico, Joplin, and Sarcovie-Reeds.

MARKETING

The marketing of the lead and zinc concentrates of the district was quite different from that practiced in the other mining centers of the country. During the early years of mining from 1848 to 1869, when only the lead ores were mined, the concentrates were either smelted by the miners themselves on crude log furnaces, or sold to small smelting companies that had built Scotch-hearth furnaces near the centers of mining. However, soon after 1870 with the completion of railroad connections to the district, zinc production expanded rapidly. Since zinc smelting is a highly specialized business, most of the major smelting companies of the country placed representatives in the district to purchase the zinc concentrates. With these larger companies paying top prices for both the zinc and lead concentrates, the local lead smelting industry began to decline. To capture some of the local zinc market, the Joplin Zinc Co. erected a zinc smelter at Joplin in 1879, but this plant failed in 1900, due largely to the high costs of transporting fuel from the coal fields of Kansas.

The prices to be paid for the lead and zinc concentrates were established each Friday through competitive bidding. Once the values were established, all of the concentrate sales were at that price. This system worked exceedingly well since all of the local mills produced a very consistent grade of both lead and zinc concentrates, containing, when clean, 80 percent as metallic lead, and 60 percent as metallic zinc. The prices paid were based on these grade standards, with penalties being charged for poor metal content, and impurities. The sales point for these transactions was the mill bin of the producer, with the smelting companies paying for the loading and haulage to the railroad, plus all further transportation and treatment charges. The smelting companies also calculated the royalties due, and deducted these amounts from the final settlement checks.

Because of the large production of lead and zinc concentrates from a district not dominated by captive mines of the smelting companies, the prices paid at Joplin were published weekly in the trade journals of the industry. For many years the prices paid at Joplin became the standards for concentrate

purchases in the mining districts of other parts of the country. Since the metallic products sold from the district were in the form of concentrates, the mining companies always expressed their mine grade values as percentages of concentrate recovery, instead of using metal recovery percentages. The difference between concentrate recovery and metal recovery have caused much confusion in statistical research. The use of concentrate recovery percentages is identical to the practice used in iron mining, where the grade values are expressed as weight-recovery percentages.

VALUE OF METALS PRODUCED

According to the U.S. Bureau of Mines the total value of the lead and zinc produced in the district from 1850 through 1970, in terms of recoverable metal, was \$2,073,200,000. Of this amount \$382,400,000 was for the recoverable lead, and \$1,690,800,000 was for the recoverable zinc. Since the figures stated above cover annual totals over a 121-year period, the total values, expressed in terms of today's dollars, would be about ten times greater, or in the neighborhood of 20 billion dollars. It is of interest to note that in 1943 the Tri-State district became the tenth mining area in the world to produce metal values in excess of one billion dollars.

MINE PUMPING

The ore deposits of the district are generally confined to areas of subsurface limestone dissolution, which represent individual water reservoirs of finite dimensions. These water zones are locally referred to as "pools", and vary widely in dimensions, ranging from small isolated water pockets covering a few acres, to larger "pools" extending over several square miles. For the most part the contained waters are largely entrapped with little, or no, lateral movement between adjacent "pools". This lack of free-flowing water circulation was a blessing to the early miners, who could dewater single ore deposits without appreciably disturbing the water levels on neighboring land parcels.

The subsurface zones of porosity are very irregular in both size and shape, and can occupy any bed, or combination of beds within the Mississippian formations. Their occurrences are extremely erratic, being situated at scattered positions in all parts of the district, and exhibit no consistent trends. They are separated from one another by varying sized areas of unaltered, mostly impervious cherty limestones, and probably occupy less than 10 percent of the district's total area. The contained water in these zones of porosity varies from scant amounts to very large volumes, depending upon the degree of dissolution, and also represents the principal sources for domestic water supplies in the rural portions of the district.

Although all of the ore deposits are localized to these zones of subsurface limestone dissolution, many of the openground areas are completely devoid of mineralization. The reasons for the absence of mineral deposits in what would otherwise be considered as favorable ground are unknown. The selectivity by the ore fluids to some zones of porosity, and not to others, may be related to subsurface undulations in the rock strata, where the ore minerals favored the structurally "high" areas, and avoided the structurally "low" areas. Also, since limestone dissolution is an ongoing process, the older

zones of porosity may have been the sites for ore deposition, while the more recent zones of rock decay may have been formed after the period of ore deposition ceased.

At the outset of mining only those ore deposits lying above the ground water table, and exposed by stream erosion, were worked. In many instances these deposits represented the upper, or oxidized portions of sulfide mineralization that continued downward below the water table. In the beginning mine dewatering was limited to the removal of surface waters, resulting from heavy rainfall and stream flooding, by utilizing large bailing buckets, and later by walking-beam pumps powered by horse whims.

As mining operations were extended deeper, large steam-powered pumps were used, which were followed by electric-powered, deep-well, turbine pumps, having capacities of several thousand gpm. Once the mines were dewatered, the inflow water, being mostly surface origin, was handled by either triplex-type pumps installed at underground sumps, or by the intermittent operation of surface turbine pumps. As a general rule the inflow or recharge water, could be handled by about 25 percent of the pumping capacity required to dewater the mine.

Mine pumping was one of the major development expenses for the operating companies of the district, and in some instances reached high proportions. In order to mine an ore deposit it was necessary to lower the water levels to the base of the ore, which usually meant to depths as great as 350 feet. In those instances where single ore deposits occupied pocket-like zones of porosity, the mine pumping was minimal, however in those areas where clusters of ore bodies were more or less interconnected, large volumes of water had to be handled. Where massive pumping efforts were required, the mining companies formed cooperative arrangements whereby the dewatering expenses could be shared.

One such cooperative effort was made during the 1935-1943 period when a consortium of the larger mining companies formed the Central Drainage District of Jasper County, Missouri, to dewater the Duenweg-Webb City-Oronogo mining field for the possible resumption of mining. This area contained a major zone of sheet-ground ore deposits that had been vigorously mined during the 1890 to 1920 period, when it was closed and allowed to flood. Mine pumping studies showed the area to cover some 14 square miles, and to consist of 8 recognizable drainage "pools", each of which required separate pumping installations. The drainage of this area to an average depth of 200 feet was completed in 6 months time, utilizing 17 deep-well pumps, having a combined capacity of 26,000 gpm. Once dewatered it was estimated that the pumping of from 5,000 to 6,000 gpm would be required to hold the water at that level. Since most of the recharge water was of surface origin, dams and levees were constructed to control the inflows from the surface drainage.

In the Picher, Oklahoma mining field an assemblage of several hundred individual ore bodies, more or less interconnected, covers an area of some 40 square miles. Mine pumping by a number of mining companies was begun here in early 1915, and by late 1916 some of the mines had been dewatered to depths of 200 feet. As the mining and pumping operations were expanded, the water levels were lowered to where some ore at depths of 350 feet was mined. After the bulk of the water had been removed, the inflow water was handled by a series of central pumping stations, the expenses for which were shared by the various operating companies. To hold the water at the agreed operating levels required

the pumping of about 20,000 gpm. With the partial shut-down of the Picher field in 1957, mine pumping was reduced about 50 percent in order to impede the rising water table for the mining of the middle and upper levels by the smaller mining companies. All mine pumping was halted in 1970, with the water level standing at a depth of 250 feet. The complete flooding of the mines did not occur until November 1979, when discharges were noted from mine openings along the lower reaches of Tar Creek. Thus it took almost 22 years for the mines to fill with water, 13 years of partial pumping, and 9 years of no pumping.

PROSPECTING

Although geological studies played an important role in the development and mining operations of the district, the major ore discoveries were stumbled into quite by accident. At the outset of mining the ore deposits were found as surface outcroppings, where they had been exposed by stream incision. As mining progressed additional ore was found by extensions from the original discoveries, and through the sinking of exploratory shafts along supposed trends. Since many of the larger ore deposits reveal no surface manifestations, a number of the subsequent discoveries were made by farmers while plowing, or by digging wells for domestic water supplies.

In about 1870 the churn drill was introduced as a prospecting tool, but was not generally accepted until about 1880, when it was used to great advantage during the development of the large "sheet-ground" mines of the Duenweg-Webb City-Oronogo trend. This machine was ideally suited for the ground conditions of the district, being self-propelled, highly mobile, economic to operate, and able to penetrate the disturbed, and broken chert zones associated with the ore deposits. Diamond drilling was tried, but failed miserably in being unable to secure meaningful core recovery in the ore-bearing mines. During succeeding years the use of the churn drill for prospecting expanded rapidly, with more than 1,000 drill rigs being employed by 1917, 800 of which were on location in the Picher, Oklahoma, mining field. These drill rigs were operated by many small, independent contractors, who owned from one to as many as 30 drill rigs.

The chief advantage of the churn drill was the ease by which the flap-valve bailing cylinder could be lowered into the drill hole after each drilling interval, so as to recover the full quantity of ore-bearing cuttings for assaying. In those areas where the ore minerals occurred in zones of loose, rotten chert (hog chaw), the churn drill could set inner strings of smaller-diameter well casing to control the caving ground. When ground conditions were particularly adverse, it was sometimes necessary to place as many as three strings of well casing, and continue drilling with smaller sized drilling tools. All prospect drilling was done with the drill hole being bailed clean at the end of each 5-foot advance, and with the rock cuttings being carefully panned for ore mineral showings. If the ore mineral showings looked encouraging, the drilling advances were reduced to 2½-foot intervals, with the entire sample being saved for precise splitting and assaying.

Since new ore deposits were very difficult to find, many of the smaller mining operators used unorthodox methods to select favorable areas to prospect. Chief among these methods was the use of fortune-tellers, of which Babbu the Hindu was well known; plus water-well witches, who claimed to have improved peach tree limbs that were tuned to find lead and zinc. In addition, the more

serious prospectors used techniques as unusual changes in the topography, perched water tables (as indicated by "craw-dad" ground), sandstone and shale inliers that might be related to collapse structures, or simply to "yardstick geology" that projected possible ore trends. Although most of these methods failed, there were enough successes to continue their use.

Land positions in the district were easy to obtain, with most landowners being anxious to participate in the royalty income. As a result of this landowner interest, large blocks of acreages could be assembled, on very reasonable terms and conditions, for large-scale "wildcat drilling". Under programs of this sort, many acres were prospected with only one drill hole, near the center of each 40-acre parcel, being put down. This wide spaced drilling failed to find and new ore.

One of the more worthwhile prospecting techniques in the district was the use of "shale drilling", wherein shallow churn drill holes were drilled to the top of the bed rock in order to map its undulations. For this type of prospecting the area being investigated was drilled on a grid-pattern spacing ranging from 200 to 400 feet, with the drill holes penetrating only the residuum, and possibly the semi-indurated shales and sandstones of Pennsylvanian age. From the depth measurements structural contour maps were prepared of the bed rock surface. Since many of the ore deposits are closely associated with truncated filled-sink structures, abrupt changes in the bed rock surface could reveal possible sites for deeper prospecting. This type of prospecting required about 16 drill holes per 40-acre tract, but costs were minimal with drilling depths seldom exceeding 100 feet. "Shale drilling" was widely used by the larger companies to prospect the upland prairie areas of the district, and was successful in finding a number of new ore deposits.

Exploratory drilling reached its peak during the middle 1920's, but fell off rapidly thereafter, when the success ratios of new ore discoveries, and the values of lead and zinc, both declined. After the peak years, the remaining drill rigs were mostly employed in mine development work searching for extensions to known ore deposits.

During the 1930's and 1940's, in an effort to revive exploratory drilling, various geophysical techniques were tested to find new areas for ore discoveries. The methods used included magnetic, gravity, self potential, electrical resistivity, electro-magnetic, and induced polarization surveys. None of these methods were able to obtain direct responses from the ore minerals themselves, but some were useful in mapping the subsurface zones of porosity that frequently form the reservoirs for ore deposits. Both the gravity and electrical resistivity surveys showed promise for porosity mapping, with the use of gravity surveys being eliminated, due to the expense for extra crews needed for accurate elevation controls. Electrical resistivity surveys, when run as profile lines on grid-patterns, offer an alternative to "shale drilling", and can be used to obtain an index of the bed rock configuration. Experimental surveys of this type have been made upon large acreages of semi-virgin ground, but follow-up drilling in the anomalous areas has been scant.

The use of geochemical analyses from soil samples for trace element surveys has been tried in a few areas on an experimental basis. The results from this testing were completely inconclusive, with the samples showing either no anomalies, or showing the erratic presence of abnormally high values for

some of the key elements. The lack of significant trace element values in most areas tested is believed to be due to the downward leaching of the soils in a temperate climate having rainfall in excess of 30 inches. The erratic high values for some of the metallic elements are thought to have resulted from soil contamination along roadways graveled with tailings from lead-zinc mills.

The future possibilities for a return to active zinc-lead mining in the district remain dim. Although wide expanses of unprospected ground are present in the areas lying between the known centers of mining, "blind-drilling" at today's cost-price ratios is not economically favorable. In the event zinc and lead again become viable commodities, it is believed that careful mapping of the subsurface porosity zones, using refined geophysical techniques, could target favorable areas for the discovery of additional ore deposits of similar grade to those previously mined.

A SUMMARY OF THE GEOLOGY OF THE ORE DEPOSITS OF THE TRI-STATE DISTRICT, MISSOURI, KANSAS, AND OKLAHOMA

Richard D. Hagni

Department of Geology and Geophysics
University of Missouri-Rolla
Rolla, Missouri 65401

INTRODUCTION

This paper provides a brief summary of information on selected geological aspects of the ore deposits of the Tri-State District, including importance, structural controls, dolomite cores, fracturing, karstification, limestone dissolution, brecciation, silicification, ore deposition, fluid inclusions, trace element compositions, isotope data, metal transport, source of metals, driving force for the ore fluids, hypotheses on ore genesis, and exploration.

IMPORTANCE

The Tri-State district was the world's largest zinc producer for nearly one-half century. During that period it was also an important producer of lead, silver, cadmium, germanium, and gallium. Both lead and zinc concentrates were made but the small amounts of copper present as chalcopyrite and enargite were not concentrates. Silver was recovered at the smelter from the lead concentrate; cadmium, germanium, and gallium were recovered from the zinc concentrate. The Tri-State district has served as the nation's largest sources of germanium even as recently as 1980 when it was recovered from zinc residues derived from the district.

Although many of the ore fields in the Missouri portion of the Tri-State district were discovered due to their exposure at the surface, the great Picher field owes its discovery to a drill rig that reportedly was stuck in the mud where the driller then decided to drill. The ore deposits of the Picher field are completely covered by Pennsylvanian shales and required drilling for their discovery and development. Almost all of the holes were drilled with churn rigs. Intensity of mineralization, host rock lithology and alteration, stratigraphic elevations, and unit thicknesses were determined from cuttings.

TRI-STATE ORE FIELDS

Ore deposits in the Tri-State

District are clustered into groups that have been referred to as fields, mining camps, subdistricts, and even districts by various authors. Their locations are shown in Figure 1 in the paper by Barks in this field guidebook.

STRATIGRAPHY

The Tri-State ore deposits occur almost entirely in Mississippian formations. The subdivision of the Boone Formation into members by McKnight and Fischer (1970), the lettering of the beds by Fowler and Lyden (1932), their thickness, general lithology, and relative importance are given in Table I.

STRATIGRAPHIC COLUMN OF CARBONIFEROUS FORMATIONS IN THE TRI-STATE DISTRICT

System	Series	Fm. /Mbr.	Bed	Thickness (m.)	Lithology	Importance as an Ore Horizon	
Pennsylvanian	Desmoinesian Morrowan & Atokan	Several Fms. & Mbrs.		0-90	Dark sh. & ss.	Minor importance	
Mississippian	Chesterian	Several Fms. & Mbrs.		0-30	Ls. cong., sh. & ss.	Minor importance	
	Meramecian	Quapaw Ls. Fm.		0-9	Ls.	Unimportant	
		Boone Formation	Moccasin Bend Mbr.	B	0-6	Ls.	Minor
				C	0-10	Ls. & chert nod.	Minor importance
				D	5.5-7	"Cotton rock" & chert	Unimportant
				E	1.5-2.5	Ls. and chert nod.	Important
				F	3.5-4.5	"Cotton rock" & chert	Unimportant
				G H	9-12	Thin bedded chert & ls.	Important
			Baxter Springs Mbr.	J	0-12	Glauconitic, shaly ls. & chert	Minor importance
				K	0-12	Ls. & chert nod.	Very important
				L	0-11	Chert	Unimportant
			Short Creek Oolite Mbr.		0-3	Oolitic ls.	Unimportant
			Osagean	Joplin Mbr.	M	0-21	Ls. & chert nod.
		Grand Falls Chert Mbr.		N	6-9	Chert	Unimportant
				O	2.5-3	Thin bedded chert & ls.	Important
				P	0-3	Chert	Unimportant
				Q	0-3	Thin bedded chert & ls.	Unimportant
		Reed Spring Mbr.		R	15-30	Ls. & dark chert nod.	Important
		St. Joe Ls. Mbr			4.5-20	Ls. & chert nod.	Unimportant
	Kinderhookian	Northview Fm.		1.5-3	Sh.	Unimportant	
		Compton Fm.		1.5-3	Ls.	Unimportant	

STRUCTURE

Although the host rocks were essentially flat lying (dip less than 1° to the southwest), a variety of structural features may have combined to funnel the ore fluids into the Tri-State district. The depth to the Precambrian basement averages about 1700-1800 feet (Brockie et al., 1968), but there is a general high in the Tri-State district (E. Kisvarsanyi, 1981). The relief on the basement surface appears to be exceptionally great and basement rocks have been encountered in drill holes as shallow as 290 feet from the surface.

Other regional structures that appear to have had a role in the structural control of the ore deposits include folds, faults, impermeable shale caps, and windows. Northwest-trending fold structures have influenced the positions of ore fields. The Joplin field, for example, has been thought to have been controlled by the Joplin anticline (Smith and Siebenthal, 1907). The Miami Trough, a rejuvenated basement fault (Brockie et al., 1968) along which tectonic brecciation and prominent post-early Pennsylvanian carbonate dissolution has occurred, appears to be an important structure that trends northeasterly through and near several of the Tri-State ore fields. The Picher field is nearly centered upon the intersection of the Miami Trough and the northwest-trending Bendelari Trough or Monocline. This spatial relationship appears to indicate an important role for such structures in the ore fluid plumbing system. Confirmation of this role is not readily observed by underground studies. For example, there is no significant increase in ore grade as one approaches exposures of the Miami Trough in the Blue Goose and Anna Beaver Mines, and the examination of the unusually coarse breccias directly associated with that fault structure gives little indication that it was any more important than the common solution collapse breccias that form the principal control for most of the ore deposits (Hagni, 1962). Yet, the presence of ore deposits to the northwest along the Bendelari Trough and to the northeast and southwest along the Miami Trough that extend beyond the main portion of the Picher field indicate that these structures clearly contributed to the plumbing system.

As is the case in all or most Mississippi Valley-type ore districts, a relatively impermeable thick section of Pennsylvanian shale occurs stratigraphically above the ore deposit. The shale is believed by most geologists to have played an important role in impeding the upward movement of the ore-bearing fluids and to have promoted the deposition of the ore minerals primarily in the Mississippian rocks beneath the shale cap.

The presence and absence of shale beneath the ore deposits may have had an even more important influence on the localization of the ore district. The Late Devonian Chattanooga Shale pinches out northward at approximately the south edge of the district. The Mississippian Northview Shale pinches out southward at the north margin of the district. The area between the pinchouts provide a window in the underlying shales that may have formed the avenue for the upward rising ore fluids (Brockie et al., 1968).

DOLomite Cores

The most important specific control for ore deposits of the Tri-State District is that of dolomite cores (Lyden, 1950, McKnight and Fischer, 1970) that are areas of coarsely crystalline dolomitized limestone that are 50 to 250 feet wide, 15 to 30 feet thick, and may extend in a circular pattern for as much as a mile or more. Individual ore runs occur along one or both margins of the dolomite cores (figure 1); where both ore runs have been mined as a single ore body the dolomite remains only in the form of central pillars. The significance of the dolomite cores as ore controls was first reported by McKnight (1950), and their character in the Picher field has been described by Lyden (1950), McKnight and Fischer (1970), Brockie et al. (1968), and Hagni (1976, 1982). The dolomite cores have originated by dolomitization of limestone due to the introduction of early fluids preceding or connected with the ore-forming fluids. The model for the dolomitizing fluids apparently was that they were introduced along fractures presumed to have been present in the center of the cores, and the fluids then migrated laterally outwards. The centers of the cores, however, commonly are massive rather than fractured and may in places consist of remnants of undolomitized limestone. These features, together with the presence of bioherms at the south margin of the district (Troell, 1962), has led to the speculation that the dolomite cores might represent dolomitized bioherms (Hagni, 1976, 1982). The similarity in size of the dolomitized cores to known bioherms in the region, the areal distribution of the dolomite, the presence of lateral shale facies, the shallow character of the depositional environment, and the presence of bioherms in the Boone Formation outside the district where its original character is less altered support such an interpretation, but partially dolomitized bioherms have not yet been observed to confirm this speculation. In the Picher field the dolomite cores commonly form circular patterns with diameters from 1/4 to about one mile. In the center of the field the intense mineralization tends to obscure some of the circular structures. At the margin of the field the ore bodies associated with these structures form accurate patterns with the open portion of the arc directed away from the center of the field.

Fracturing

The most intense fracturing has occurred at the margins of the dolomite cores where the dolomite is in contact with rock that originally was limestone but which subsequently was silicified to form jasperoid (figure 1). The fractures are mainly vertical, follow the curved margins of the dolomite cores, and are readily observed in the working faces and backs especially where they are filled with late-deposited pink dolomite. The fractures probably developed during a period of slight flexing and were localized at the dolomite-limestone boundary due to their difference in the response of the two lithologies to gentle folding. Part of the fracturing of chert nodules apparently took place at this time. These fractures appear to have provided the major arteries of the plumbing system for host rock preparation and the introduction of the subsequent ore-forming fluids.

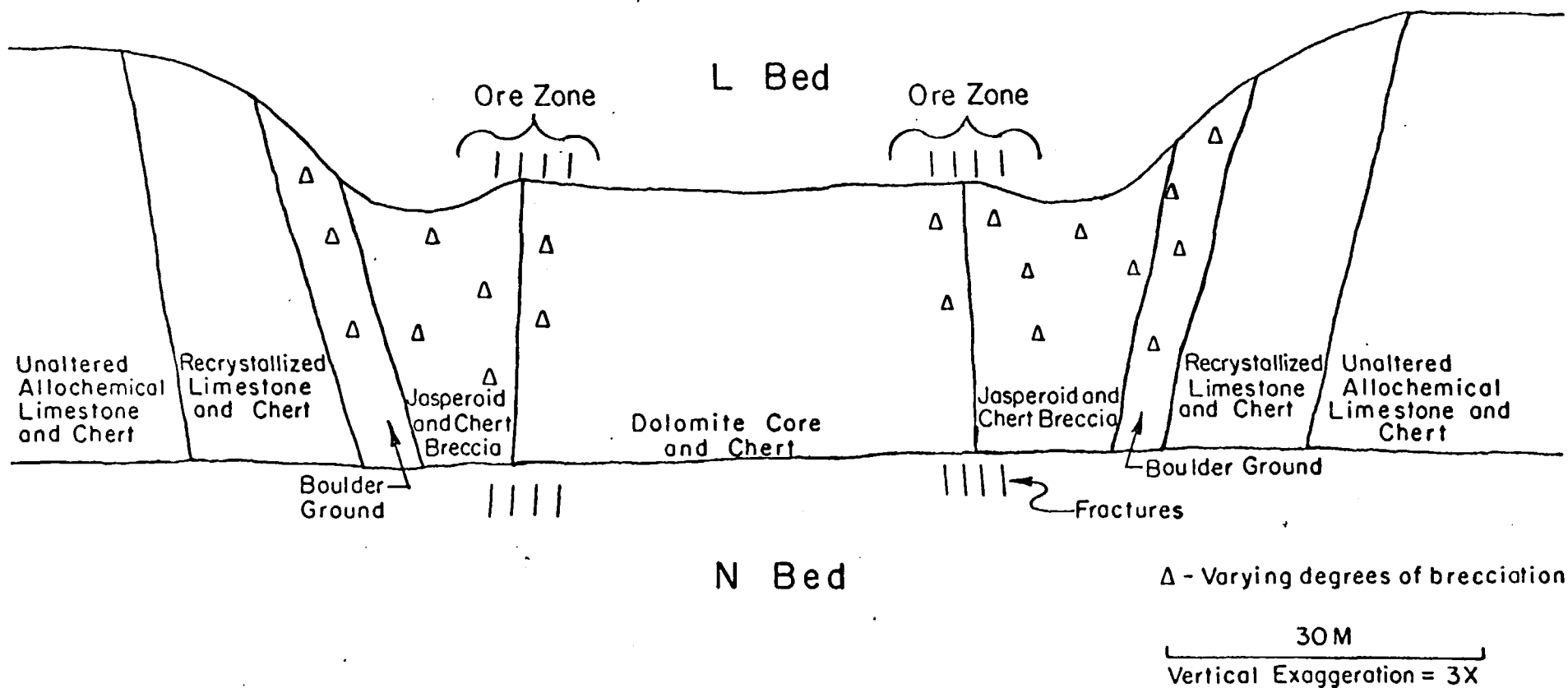


Fig. 1 Generalized Section through Small Scale Zoning in M Bed,
 Eastern Portion of Picher Field.
 (Modified after Mc Knight and Fischer, 1970; Lyden 1950)

KARSTIFICATION

The unconformity between the Mississippian and the Pennsylvanian is known to exhibit karstification effects that extend regionally beyond the Tri-State district. Within the district, karstification associated with that erosional contact, and with the contact between the Warsaw and the Chester, and perhaps younger unconformities appear to have been associated with the dissolution of the Mississippian formations that initiated the ground preparation for the introduction of the subsequent ore fluids. The ore fluids continued the process of dissolution of the host rocks and they may have played the dominant role in solution thinning and brecciation of the ore-containing beds.

ORE FLUID INTRODUCTION

The introduction of ore fluids had a pronounced effect upon the Mississippian host rocks, including 1) limestone dissolution, 2) brecciation, 3) silicification, and 4) limestone alteration. Dolomitization may have been a manifestation of the earliest ore fluid introduction.

Limestone Dissolution

Within the ore fields, the Mississippian limestones have been greatly affected by introduced fluids. Where the mineralization is greatest, the host rock limestones have been completely dissolved and removed, leaving a residual chert breccia that is cemented by introduced sulfide ore minerals and jasperoidal silica. For example, the M bed limestone, the main ore horizon in the Picher field, is more than 100 feet thick outside the field but has commonly been thinned to 20 feet or less within the field and may be only five feet thick in areas with the highest ore grades. Isopachous maps for the M bed have been prepared for the Picher and Galena field that document these thickness variations and quantitatively evaluate the extent of limestone dissolution (Hagni and Desai, 1966).

Brecciation

The Tri-State ore deposits are typically contained in chert breccias that are cemented by sulfide minerals and jasperoid. Their initial development probably began with karstification, but their development was greatly enhanced by the introduction of the ore fluids. The term hydrothermal karstification has been applied to the process of development of similar breccias in the Upper Silesian zinc deposits in Poland, which have been well described by Maria Sass-Gustkiewicz (1983). Slight flexing of the beds in the district probably contributed to their fracturing prior to solution collapse during karstification and hydrothermal fluid action. Noting the small size of the breccia clasts in the Tri-State district, Sawkins (1969) suggested that much of brecciation was due to alkali-chert and alkali-carbonate reactions that are well known in the concrete industry because they cause aggregate fragments to fracture and rupture the concrete. Ohle (1985) has recently supported this concept of chemical brecciation and believes that it contributes to the results of solution collapse and gravity shattering.

Silicification

The Tri-State ore deposits are characterized by the presence of enormous amounts of introduced silica in the form of jasperoidal quartz and some larger quartz crystals. Jasperoid consists of very fine-grained quartz that has an appearance similar to chert, but it can be distinguished by its color, grain size, associated sulfide minerals, and mode of occurrence. In contrast to the tan to white colors of most chert (although R bed chert is dark), jasperoid typically is dark grey to black in color. Jasperoid is slightly coarser grained than chert; under the microscope jasperoidal quartz grains can be seen to exceed about 15 μm and exhibit prismatic shapes; most quartz grains in chert are smaller, have equant shapes, and may have minor associated chalcedony. These grain size differences also can be partly detected with a hand lens where some of the coarser quartz crystals in jasperoid can be perceived. Chert does not contain disseminated sulfides, except for pyrite, whereas jasperoid almost universally and characteristically contains disseminated pyrite, marcasite, sphalerite, and minor galena. Finally, chert forms beds, lenses, and nodules that are essentially conformable to the enclosing limestones, whereas jasperoid forms bodies that are transgressive to the host rocks and locally may be observed to vein the host rock (Hagni, 1976).

Jasperoid cements chert breccia fragments in the ore zones, extends outward into the limestone as a metasomatic siliceous replacement (figure 1), and partially replaces carbonate in the dolomite cores.

The degree of silicification in the Tri-State District contrasts with that present in most Mississippi Valley-Type districts, indicating some difference in the Tri-State ore fluids from those in other districts. One idea is that the ore fluids derived their silica from the partial dissolution of the abundant chert in the Mississippian host rocks and that the silica was subsequently precipitated as jasperoid (Hagni, 1976). Locally, however, silicification is intense at the margins of some ore bodies in the Viburnum Trend.

Limestone Alteration

The host rock limestones have been altered even beyond the effects of silicification (Hagni and Saadallah, 1965). Limestones distal from the ore deposits exhibit petrographic textures comprised especially of crinoidal fossil fragments. Within a distance of about 200 feet from the deposits, the limestone textures change to one comprised mainly of sparry calcite (figure 1). By cathodoluminescence microscopy, irregularly shaped replacement remnants of the crinoids, which have a darker reddish cathodoluminescence, can be detected in the sparry calcite that exhibits a lighter reddish cathodoluminescence, and all degrees of the replacement of crinoidal limestone by sparry calcite can be recognized (Hagni, in press).

ORE DEPOSITION

The Tri-State ore deposits consist primarily of the sulfides, sphalerite, galena, chalcopyrite, pyrite, and marcasite, and the gangue minerals quartz, dolomite, and calcite. Small amounts of wurtzite, enargite, luzonite, barite, and aragonite occur locally. The ore minerals were deposited especially as open space fillings in vugs and other openings, but finer grained sulfides also are disseminated where they replace limestone along with jasperoid adjacent to the coarser grained sulfide vug-linings.

The general sequence in which the minerals were deposited was the following: dolomite, jasperoidal quartz, sphalerite, galena, chalcopyrite, marcasite, pyrite, enargite and luzonite, barite, and calcite. The detailed paragenetic sequence is more complicated because each of the minerals were repetitively deposited, and at least seven cycles of mineralization can be distinguished (Hagni and Grawe, 1964). For example, one can readily observe that early yellow disseminated sphalerite is coated by a later growth of main stage brown vug-filling sphalerite, and that a younger generation of smaller reddish brown sphalerite has been deposited upon the brown sphalerite. Each of these generations of sphalerite are characterized by the range of temperature at which they were deposited and by their trace element assemblage.

Barite was absent from most Tri-State ore deposits, especially from the Picher field, but it formed a minor late-deposited mineral in some deposits and was abundant in some mines such as those at Thoms, Kansas and some other deposits at the north edge of the district.

Although fluorine has been detected at the smelter, fluorite has not been recognized in the ores.

FLUID INCLUSIONS

The study of fluid inclusions in the Tri-State ore minerals has provided information on the temperatures at which those minerals were deposited and the salinity of the ore fluids.

Temperatures

The total range of deposition temperatures for Tri-State ores is from 135°C down to less than 50° (Hagni and Wei, 1977). Main stage sphalerite was deposited from 135°C to 90°C during declining temperatures that appear to have fluctuated 15-20°C during that decline. Yellow disseminated sphalerite was deposited during a slightly narrower and lower temperature range, 120-85°C. Later red sphalerite has formed at temperatures slightly higher than those toward the end of brown sphalerite deposition. Because the fluid inclusions in Tri-State barite do not contain bubbles, the temperature of barite deposition is judged to have formed below about 50°C.

Temperature measurements by Schmidt (1962) were interpreted to indicate a general decline away from the Miami Trough; for main stage brown sphalerite he found average temperatures of 115°C at 15 feet vs. 104°C at 30 feet from the trough. Fluid inclusions temperatures measured for calcite were 68-52°C.

Measurements of very small fluid inclusions in Tri-State dolomite crystals have indicated temperatures and salinities similar to those measured for the sulfide minerals (Rowan, in press).

Salinities

Early studies of fluid inclusions in Tri-State sulfides showed that their salinity was so high that halite precipitated from the fluid upon its evaporation after cleaving galena and sphalerite (Newhouse, 1933). Subsequent freezing measurements of the fluid in inclusions in sphalerite by Roedder (1967) indicate that the salinities of the ore fluids were very high, about 30% NaCl equivalent.

TRACE ELEMENTS

The trace element compositions of sphalerite and galena have been studied because of their economic importance and geologic interest. Silver contained in Tri-State galena was recovered at the smelter. Cadmium, germanium, gallium, and indium (?) were recovered from sphalerite.

Sphalerite

Trace element data for a large number of analyses have recently been published for Tri-State ore minerals and compared with other Mississippi Valley-type (MVT) ore deposits (Hagni, 1983). A total of 187 analyses of Tri-State sphalerite crystals from all generations of deposition contain an average of 0.47% Cd, 0.27% Fe, 134 ppm Ge, 255 ppm Ga, 5.1 ppm Ag; 92 analyses gave an average of 18 ppm Ni, and 0.2 ppm Co. The cadmium content is very similar to that of sphalerite in many MVT districts: 1) Northern Arkansas zinc district (0.54% Cd) (in fact that district is very similar to Tri-State with respect to its mineralogy and the character of those minerals), 2) Southern Illinois-Kentucky (0.37%), 3) East Tennessee (0.42%), 4) Central Tennessee (0.40%), 5) Upper Silesia, Poland (0.46%), and perhaps Laisvall, Sweden (0.30%). It is slightly higher than that of some Mississippi Valley-type deposits (e.g., 1) Wisconsin-Illinois, 2) Austinville, VA, 3) Friedensville, PA, 4) Pine Point, NWT, and 5) the European Alpine deposits). It is significantly lower than sphalerite from the Southeast Missouri Lead District (0.86%) and vein deposits in central Kentucky and Tennessee (1.33%).

The iron contents of sphalerite for some MVT deposits (Northern Arkansas, East Tennessee, Central Kentucky-Tennessee veins, and the European Alpine deposits) are similar to that of Tri-State sphalerite, but others have higher values that range from about 0.8% (Southeast Missouri, Wisconsin-Illinois, Southern Illinois-Kentucky) to 2.2% (Southern Pennine, England; Upper Silesia, Poland; western Canada).

The average germanium content for sphalerite in MVT deposits ranges from 60 to 400 ppm. Southeast Missouri Lead District sphalerite averages (114 ppm) close to that for Tri-State sphalerite. Gallium contents in Tri-State sphalerite are at the top of the range for MVT deposits, and exceed those of sphalerite in Southeast Missouri (155 ppm) and in the Upper Silesian deposits of Poland which have the lowest gallium content (15 ppm) of MVT deposits. The

average gallium to germanium ratio (1.9) in Tri-State sphalerite is higher than that reported by Möller et al. (1983) for sphalerite in the Alpine-type deposits at Bleiberg, Austria, Raibl, Itali, and Mezica, Yugoslavia.

The content of silver in sphalerite from Tri-State is very low and similar to that in sphalerite from most MVT deposits. Sphalerite from some MVT deposits has a higher silver content; 163-200 for Upper Silesia, Poland and Southern Pennine, England; 434 ppm for the Southeast Missouri Lead District.

The content of cobalt and nickel in sphalerite is low in all MVT districts, except for the Southeast Missouri Lead District with an average of 391 ppm Ni and 490 ppm Co.

Significant trace element variations occur between sphalerite crystals of different paragenetic positions. Germanium and gallium contents are about two to four times higher in early yellow and late red sphalerite than in main stage brown sphalerite. Rare stalactitic sphalerite contains three to ten times higher germanium, but it is similar to the lower gallium contents, as compared to those three earlier generations of sphalerite. Sphalerite in sulfide concretions in the Pennsylvanian shales above the ore deposits have similar gallium but very low germanium contents. Red sphalerite has about 7/10's the cadmium content of yellow and brown sphalerites; stalactitic sphalerite has 3/10's that of the earlier deposited sphalerites. The silver content of stalactitic sphalerite is ten times that of most Tri-State sphalerite. Within single crystals that belong to the main stage of sphalerite deposition, silver, germanium, and perhaps gallium contents increase and cadmium decreases outward.

Galena

Trace element analyses have also been published for Tri-State galenas and compared with other MVT ore deposits (Hagni, 1983). A total of 63 analyses of Tri-State galena crystals from all generations of deposition contain an average (in ppm) of 11.2 Ag, 49 Sb, 52 Bi, and 9.6 Cu. The silver content is very similar to that of galena in Northern Arkansas (9 ppm), Wisconsin-Illinois (15.7), and Austinville (15), but nearly an order of magnitude less than that in the Southeast Missouri Lead District (85) and much less than Southern Illinois-Kentucky (149), Silesia, Poland (173), and Laisvall, Sweden (192). The antimony content is less than that in galena in other MVT districts, such as Southeast Missouri (171 ppm). Bismuth content in Tri-State galena is about the same as that in Southeast Missouri (50) but less than that in Southern Illinois-Kentucky (139) galena.

ISOTOPE DATA

Lead

Although lead isotopes have been used to date a wide variety of rocks and ores elsewhere, the lead isotope composition of Tri-State galena using a single-stage model gives anomalous values with ages of lead deposition in the future. This type of anomalous lead isotope ratios has been called J-type lead, the "J" representing Joplin. The range of ratios within a single galena crystal from its center to edge would correspond to a period of deposition of 100 million years (Cannon et al., 1963). Some have interpreted J-type leads to

have formed by the mixing of leads in various proportions from two sources, a normal lead and a radiogenic lead, the latter from a uranium-rich environment. In contrast, Pelissonnier (1983) notes that J-leads occur only in ore deposits that occur above Precambrian basements and maintains that J-leads form by differential leaching in source areas with high lead and uranium contents, such as Precambrian granitic basements. He postulates early leaching conditions under which lead was soluble and uranium was insoluble, leading to a subsequent high U-Pb ratio in the source area.

Sulfur

Very limited sulfur isotope analyses for Tri-State sulfide minerals have given a fairly wide range of values (Jensen, 1967). Most Mississippi Valley-type deposits (e.g., Southeast Missouri, Illinois-Wisconsin, and Pine Point Districts) have very wide sulfur isotope ratios with a peak between +15 and +20 (Jensen, 1967; Ohmoto and Rye, 1979). Such data had been interpreted to indicate a sulfur derivation by bacterial reduction (Jensen, 1967). More recently, inorganic processes have been shown to be capable of significant sulfur isotope fractionation, and mixing of sulfur from two different sources, such as evaporites and other sedimentary rocks, may explain the ratios (Ohmoto and Rye, 1979).

METAL TRANSPORT

The form in which the metals were transported to the eventual sites of deposition has been a subject of considerable interest. The early idea that the metals were carried in solution as simple ions is not supported by their low solubilities especially in low temperature fluids. Subsequent research has shown that most metals are much more soluble as chloride complexes (Helgeson, 1969) and as bisulfide complexes (Barnes, 1967), and two somewhat opposed schools of thought emerged in support of one or the other of these two mechanisms of ore transport. Bisulfide complexes have the favorable aspect that they provide a source of reduced sulfur in the same fluid that transports the metals, but they require alkaline conditions and they are much more stable at relatively high temperatures. Chloride complexes are supported by the high concentration of chlorine in the brines in fluid inclusions in MVT minerals. Recent interest has focused upon the possible role of organic complexing in metal transport. Support for the possible importance of organic complexes comes from the presence of some form of organic matter in most MVT districts. Petroleum was present in the upper beds and dripped down on the walls of the mine workings in the Tri-State district. Petroleum occurs in fluid inclusions in fluorite in the Southern Illinois-Kentucky district. Asphalt flows through the deposits at Pine Point, Northwest Territories in the middle warm portion of summer days. Bitumen is locally present in the Southeast Missouri Lead District and has been found to occur as a late phase at the Magmont mine (Marikos, 1986). Although many metal organic complexes are very soluble and have the potential to form viable transport mechanisms (Giordano and Barnes, 1981; Giordano, 1985), the specific complexes and their actual role remains to be determined.

SOURCE OF THE METALS

The source of the metals has remained an elusive subject. Early ideas involved the leaching of trace amounts of metals from the host rocks by lateral secretion, and the contribution of metals from an undisclosed igneous source by magmatic hydrothermal fluids. Recent interpretations have sought a source in the shaly rocks in subjacent sedimentary basins. Some individuals would derive most of the metals from a basinal source, but would involve small contributions of other metals by dissolution of host rock constituents, minor magmatic contributions during the fluid transport from the basin to the site of deposition, and dissolution of metals from basement rocks.

DRIVING FORCE FOR THE ORE FLUIDS

The driving force that moved the ore fluids out of the sedimentary basins and to the sites of ore deposition has been a subject of recent interest. Until recently, the principal driving force was believed to be that of sediment compaction during basin subsidence. Overpressuring, which has been thought to be important by Sharp (1978) and Cathles and Smith (1983), would result in an episodic dewatering of the basinal sediments and would accord well with the repeated mineral paragenetic sequence. Recent numerical modeling by Garvin (1985) for the Pine Point district and by Bethke (1986) for the Wisconsin-Illinois district has rejected a compaction-driven brine flow for those districts and supported a gravity-driven groundwater flow. The topographic uplift of the Pascola Arch in post-Early Permian to pre-Late Cretaceous time is postulated to initiate groundwater movement toward the Wisconsin-Illinois district. Bethke notes, however, that a compaction-driven model may be viable for ore districts associated with the Ouachita basin because of its greater shale content and a rapid rate of subsidence.

The potential for a driving mechanism to have developed from radioactive decay of uranium and thorium is discussed in the section on genesis.

HYPOTHESES ON ORE GENESIS

Hypotheses on the genesis of the ore deposits of the Tri-State District have followed the trend of thinking on MVT and other ore deposits. The changes in ideas reflect the acquisition of new geological data and provide an interesting contrast in hypotheses as our views have been modified through time.

Many of the early investigators, including some individuals close to the deposits at the Missouri Geological Survey and the Missouri School of Mines (UMR), believed the ore deposits to have formed from cold downward percolating waters; the volume by Siebenthal (1915) is an example of this school of thought. Features supporting this hypothesis were the closeness of the deposits to the earth's surface, the fact that traces of the metals were present in the host rock in many places that could have provided a source.

The groundwater or lateral secretion hypothesis gradually gave way to that of magmatic hydrothermal (telethermal) fluids as it was recognized that heated waters were much better fluids for the transport of metal ions, and that cold waters could dissolve only minimal amounts of metals, especially lead. Fluid

inclusion temperature measurements for sphalerite also supported this concept. Furthermore, the concept of magmatic hydrothermal fluids had gained wide support, especially in the United States, for metal transport and the deposition ore deposits of nearly every variety.

The currently favored hypothesis involves brines that were derived from subjacent sedimentary basins. This idea originated from the measurements of the salinity of the fluid inclusions in minerals from MVT deposits which showed that the ore fluids had a much greater salinity (about 30%) than that (usually less than 5%) of the fluid inclusions minerals from typical magmatic hydrothermal ore deposits (Roedder, 1967), and from the comparison of the salinity and the compositions and ratios of the various salts in the fluid inclusions with those of connate brines association with oil fields (White, 1958). The fact that the metals are very soluble in such brines as chloride complexes also has lent great support to this hypothesis (Helgeson, 1969). These results were so convincing that most geologists now believe that MVT deposits were deposited from basin-derived waters. Some of the questions that remain are how the ore fluids acquired their high salinities and how they acquired and maintained their elevated temperatures.

A new genetic hypothesis for some types of ore deposits has received special attention as the result of a recent conference at St. Austell, Cornwall, England (Halls, 1985) and this idea may merit some consideration for Mississippi Valley-type ore deposits. Granites of Variscan age in the Cornwall tin district have provided significant amounts of heat to meteoric groundwaters long after their final solidification. The heat produced by such granites, called high heat production granites, has resulted from radioactive decay of uranium and thorium, which are abundant in those granites. Groundwater circulation cells were promoted by the heat contribution, and they operated over a very long period of time. Although the cassiterite deposition at Cornwall is thought to have taken place from magmatic hydrothermal fluids associated with the granite intrusions, subsequently deposited uranium minerals and part of the development of the china clay deposits is now thought to have resulted from deeply circulating groundwaters that were heated by radioactive decay over a period of time that extended from Pennsylvanian through Tertiary and to the Pleistocene. Even today, brines in some of the Cornish mines have groundwaters with temperatures of about 50°C. Numerical modeling by Fehn (1985) indicates that groundwater temperatures produced by radioactive could be expected to reach about 50°C, and other factors such as a sizable overburden and additional heat contributed from some regional thermal source can elevate the temperature to as much as 200°C. Some of the Precambrian granites exposed in the St. Francois Mountains, such as the Graniteville granite, have unusually high uranium (14 ppm) and thorium (42 ppm) contents. Similar tin granites are present in the buried basement elsewhere in Missouri (E. Kisvarsanyi, 1981). Could granites or other igneous rocks with high radioactive element content in the Precambrian basement in the Tri-State District have promoted the development of heated groundwater circulation cells? If such an idea has any application to the Tri-State District it would appear that an additional source of heat would be required to raise the temperatures to those recorded in the fluid inclusions.

EXPLORATION

Among other relatively recent aspects of exploration in the Tri-State district were the drilling in the Oswego, Kansas area, and the drill testing of the deeper Bonneterre Formation and Precambrian basement.

Late in the life of the Tri-State district, Eagle-Picher drilled five deep holes into the Precambrian basement to test the lower Paleozoic formations, including the Bonneterre that is the important host rock in the Southeast Missouri Lead District, and to examine the basement. The Bonneterre was found to be thin and contain only traces of galena.

After the closure of the Picher field, Kerr-McGee selected the Oswego area, based upon geological concepts, for exploratory drilling. Their drilling, and subsequently that by other companies, outlined an ore deposit in an area where mineralization was not formerly known to exist. Although the deposit apparently is of small tonnage and a grade insufficient to warrant mining at present zinc prices, its discovery has demonstrated the potential for the discovery of additional ore deposits under a cover of Pennsylvanian shale in the district.

A paper presented by Miller (1986) at the September 7-10, 1986 Society of Mining Engineers' annual fall meeting in St. Louis summarized the results of his dissertation research conducted at the University of Georgia and dealt with a computer simulation of drilling patterns for the Tri-State District. The computer simulation developed probability data that were used to calculate the chance of discovering an ore field in the district. Various drilling patterns that differed in drill hole spacings were compared with the locations of mined ore fields. He concluded that holes on eight mile centers would have been best to discover the Picher field; four mile centers to discover the smaller Webb City and Joplin fields. Such wide spacings differ markedly with former drilling patterns in the district, contrast to actual discovery histories, and may form the subject for discussion.

BIBLIOGRAPHY

- Barnes, Hughes L. and G. K. Czamanske (1967) Solubilities and Transport of Ore Minerals, in H. L. Barnes (ed.) *Geochemistry of Hydrothermal Ore Deposits*, Holt, Rinehart, and Winston, New York, p. 334-381.
- Bethke, Craig M. (1986) Hydrologic Constraints on the Genesis of the Upper Mississippi Valley Mineral District from Illinois Basin Brines, *Econ. Geol.* 81:233-249.
- Brockie, Douglas C., Hare, Edward H., Jr., and Dingess, P. Richard (1968) The Geology and Ore Deposits of the Tri-State District of Missouri, Kansas, and Oklahoma, in John D. Ridge (ed.) *Ore Deposits of the United States, 1933-1967*, AIME, New York, p. 400-430.
- Cannon, R. S., Jr., Pierce, A. P., and Delevaux, M. (1963) Lead Isotope Variations with Growth Zoning in a Galena Crystal, *Science* 142:574-576.
- Cathles, Larry M. and Smith, A. T. (1983) Thermal Constraints on the Formation of Mississippi Valley-Type Lead-Zinc Deposits and Their Implications for Episodic Basin Dewatering and Deposit Genesis, *Econ. Geol.* 78:983-1002.

- Fehn, Udo (1985) Post-Magmatic Convection Related to High Heat Production in Granites of Southwest England: A Theoretical Study, in Christopher Halls, (ed.) High Heat Production (HHP) Granites, Hydrothermal Circulation and Ore Genesis, The Institution of Mining and Metallurgy, London, p. 99-112.
- Fowler, George M. and Lyden, Joseph P. (1932) The Ore Deposits of the Tri-State District, AIME Trans. 102:206-251.
- Garvin, Grant (1985) The Role of Regional Fluid Flow in the Genesis of the Pine Point Deposit, Western Canada Sedimentary Basin, Econ. Geol. 80:307-324.
- Giordano, T. H. and Barnes, H. L. (1981) Lead Transport in Mississippi Valley-Type Ore Solutions: Econ. Geol. 76:2200-2211.
- Giordano, T. H. (1985) A Preliminary Evaluation of Organic Ligands and Metal-Organic Complexing in Mississippi Valley-Type Ore Solutions, Econ. Geol. 80:96-106.
- Hagni, Richard D. (1962) Mineral Paragenesis and Trace Element Distribution in the Tri-State Zinc-Lead District, Missouri, Kansas, Oklahoma, Ph.D. dissertation, University of Missouri, 252 p.
- Hagni, Richard D. (1982) The Influence of Original Host Rock Character upon Alteration and Mineralization in the Tri-State District of Missouri, Kansas, and Oklahoma, U.S.A., in G. C. Amstutz, A. El Goresy, G. Frenzel, C. Kluth, G. Moh, A. Wauschkuhn, and R. A. Zimmermann (eds.) Ore Genesis - The State of the Art, Springer-Verlag, Berlin, p. 97-107.
- Hagni, Richard D. (1983) Minor Elements in Mississippi Valley-Type Ore Deposits: Chapter 7, in W. C. Shanks, III (ed.) Cameron Volume on Unconventional Mineral Deposits, Soc. Econ. Geol. - Soc. Min. Eng., AIME, New York, p. 71-88.
- Hagni, Richard D., Industrial Applications of Cathodoluminescence Microscopy, in Richard D. Hagni (ed.), Process Mineralogy VI, AIME, New York, NY (in press).
- Hagni, Richard D. and Desai, Arvind A. (1966) Solution Thinning of the M Bed Host Rock Limestone in the Tri-State District, Missouri, Kansas, Oklahoma, Econ. Geol. 61:1436-1442.
- Hagni, Richard D. and Grawe, Oliver R. (1964) Mineral Paragenesis in the Tri-State District, Missouri, Kansas, Oklahoma, Econ. Geol. 59:449-457.
- Hagni, Richard D. and Saadallah, Adnan A. (1965) Alteration of Host Rock Limestone Adjacent to Zinc-Lead Ore Deposits in the Tri-State District, Missouri, Kansas, Oklahoma, Econ. Geol. 60:1607-1619.
- Hagni, Richard D. and Wei, Chi-Sheng (1977) Ore Microscopy and Fluid Inclusion Geothermometry of Sphalerite from the Tri-State Zinc-Lead District, Missouri, Kansas, and Oklahoma (abstract), Annual Meetings of the Geological Association of Canada, Mineralogical Association of Canada, Society of Economic Geologists, and Canadian Geophysical Union, Program with Abstracts, Vol. 2, Vancouver, British Columbia, p. 22.

Halls, Christopher (ed.) (1985) High Heat Production (HHP) Granites, Hydrothermal Circulation and Ore Genesis, The Institution of Mining and Metallurgy, London, 593 pp.

Helgeson, Harold C. (1969) Thermodynamics of Hydrothermal Systems at Elevated Temperatures and Pressures, *Am. J. Sci.* 267:729-804.

Jensen, M. L. (1967) Sulfur Isotopes and Mineral Genesis, Chapter 5 in Barnes, Hubert L. (ed.) *Geochemistry of Hydrothermal Ore Deposits*, Holt, Rinehart and Winston, New York, p. 143-165.

Kisvarsanyi, Eva B. (1981) Geology of the Precambrian St. Francois Terrane, Southeastern Missouri, Missouri Department of Natural Resources, Division of Geology and Land Survey, Report of Investigation 64, 58 p.

Lyden, Joseph L. (1950) Aspects of Structure and Mineralization used as Guides in the Development of the Picher Field, *AIME Trans.* 187:1251-1259.

Marikos, Mark A. (1986) Relation of Bitumen to Ore in the Magmont West Orebody, Viburnum Trend, Missouri, in Walter E. Dean (ed.) *Proceedings of the Denver Region Exploration Geologists Society Symposium, Organics and Ore Deposits*, Wheat Ridge, Colorado, p. 157-164.

McKnight, Edwin T. and Fischer, Richard P. (1970) Geology and Ore Deposits of the Picher Field, Oklahoma and Kansas, U.S.G.S. Prof. Paper 588, 165 p.

McKnight, Edwin T. (1950) The Tri-State Region, in Charles H. Behre, Jr., Allen V. Heyl, and Edwin T. McKnight (eds.), *Zinc and Lead Deposits of the Mississippi Valley*, International Geological Congress Report 18, part 7, p. 57-58.

Miller, J. W., Jr. (1986) Computer Simulation of Drilling Patterns for Mississippi-Valley Deposits, Society of Mining Engineers, AIME, Fall Meeting, Program and Abstracts, p. 31.

Möller, P., Dulski, P., and Schneider, H.-J. (1983) Interpretation of Ga and Ge Content in Sphalerite from the Triassic Pb-Zn Deposits of the Alps, in H.-J. Schneider (ed.) *Mineral Deposits of the Alps and of the Alpine Epoch in Europe*, Springer-Verlag, Berlin, p. 213-222.

Newhouse, W. H. (1933) Temperature of Formation of the Mississippi Valley Lead-Zinc Deposits, *Econ. Geol.* 28:744-750.

Ohle, Ernest L. (1985) Breccias in Mississippi Valley-Type Deposits, *Econ. Geol.* 80:1736-1752.

Ohmoto, Hiroshi and Rye, Robert O. (1979) Isotopes of Sulfur and Carbon, Chapter 10 in Hubert L. Barnes, *Geochemistry of Hydrothermal Ore Deposits*, 2nd Edition, p. 509-567.

Pelissonnier, Hubert (1983) Metallogenic Significance of J-Lead, in Geza Kisvarsanyi, Sheldon K. Grant, Walden P. Pratt, and John W. Koenig (eds.) *International Conference on Mississippi Valley Type Lead-Zinc Deposits*, University of Missouri-Rolla, Rolla, Missouri, p. 216-225.

Roedder, Edward (1967) Environment of Deposition of Stratiform (Mississippi Valley-Type) Ore Deposits, from Studies of Fluid Inclusions, in John S. Brown (ed.) Genesis of Stratiform Lead-Zinc-Barite-Fluorite Deposits (Mississippi Valley Type Deposits) -- A Symposium, New York, Econ. Geol. Monograph 3:349-361.

Rowan, Lanier (in press) A Study of Fluid Inclusions within Cathodoluminescent Zones in Gangue Dolomites, Viburnum Trend Pb-Zn District, Southeast Missouri, in Richard D. Hagni (ed.), Process Mineralogy VI, AIME, New York, NY.

Sass-Gustkiewicz, Maria (1983) Zinc-Lead Ore Structures from Upper Silesian Region in the Light of Solution Transfer, in Geza Kisvarsanyi, Sheldon K. Grant, Walden P. Pratt, and John W. Koenig (eds.) International Conference on Mississippi Valley Type Lead-Zinc Deposits, University of Missouri-Rolla, Rolla, Missouri, p. 20-26.

Sawkins, F. J. (1969) Chemical Brecciation, an Unrecognized Mechanism in Breccia Formation?, Econ. Geol. 64:613-617.

Schmidt, R. A. (1962) Temperatures of Mineral Formation in the Miami-Picher District as Indicated by Liquid Inclusions, Econ. Geol. 57:1-20.

Sharp, J. M. (1978) Energy and Momentum Transport Model of the Ouachita Basin and its Possible Impact on Formation of Economic Mineral Deposits: Econ. Geol. 73:1057-1068.

Siebenthal, C. E. (1915) Origin of the Zinc and Lead Deposits of the Joplin Region - Missouri, Kansas, and Oklahoma, U.S. Geol. Surv. Bull. 606, 283 p.

Smith, W. S. Tangier and Siebenthal, C. E. (1907) Description of the Joplin District in Geologic Atlas of the United States, U.S. Geological Survey Folio 148, 20 p.

Troell, Arthur R. (1962) Lower Mississippian Bioherms of Southwestern Missouri and Northwestern Arkansas, Jour. Sed. Pet. 32:629-644.

White, Donald E. (1958) Liquid of Inclusions in Sulfides from Tri-State (Missouri-Kansas-Oklahoma) is probably Connate in Origin (abstract), Geol. Soc. Amer. Bull. 69:1660-1661.

POST-MINING HAZARDS OF THE KANSAS-MISSOURI-OKLAHOMA
TRI-STATE ZINC-LEAD MINING DISTRICT

W. M. Dressel¹, Michael C. McFarland² and James C. Brown, Jr.²

¹307 Christy Drive
Rolla, Missouri 65401

²Division of Geology and Land Survey
Department of Natural Resources
P.O. Box 250
Rolla, Missouri 65401

ABSTRACT

Over 14,000 prospect and mining shafts were sunk in the Tri-State Zinc-Lead Mining District and approximately 500 million tons of ore were removed from the subsurface since ore was discovered in 1848. In a study done by the Geological Surveys of Missouri, Kansas, and Oklahoma for the U.S. Bureau of Mines in 1983, it was shown that there are currently over 1500 open mine shafts and nearly 500 subsidence collapse features in the abandoned Tri-State District.

Eleven open shafts, in Galena, Kansas, were closed during a Bureau of Mines Demonstration Project using inverted pyramid shaped plugs. One shaft was closed by backfilling, and two were closed with reinforced concrete caps.

HISTORY

(References 3, 9, 10, 12, 15, 19, 20, 27)

The Tri-State Zinc-Lead District includes the mineralized region on the northwest flank of the Ozark Mountains in southwest Missouri, southeast Kansas and northeast Oklahoma.

The first mining was done in the present townsite of Joplin, Missouri in 1848. Originally, the ore was mined for its lead content but, with the development of the railroads and the availability of smelters, zinc production began in 1872. The first zinc concentrates were shipped to LaSalle, Illinois with shipments going to the smelter in Weir City, Kansas constructed in 1873.

The discovery of the deposits in Galena, Kansas in 1877 gave an impetus to mining and the sale of concentrates was further facilitated by the erection of the R. Lanyon & Co. Zinc Works in Pittsburg, Kansas in 1878.

In 1891, lead mining began in Indian Territory (northeast Oklahoma), near Peoria, and ore discoveries followed near Lincolnville, Miami and Picher. Large scale mining started in the Miami-Picher Field in 1916.

Mining ceased in the Missouri portion of the district in 1957 although 15 tons of zinc was reportedly produced in 1967. Oklahoma and Kansas production of lead and zinc came to an end in 1970. Production statistics for lead and zinc during the period from 1850 to 1970 are shown below:

TRI-STATE MINING DISTRICT METAL PRODUCTION, 1850-1970

Short Tons of Recoverable Metal

KANSAS	691,338	2,900,000
MISSOURI	885,390	3,618,930
OKLAHOMA	1,306,679	5,219,998
TOTAL	2,883,407	11,738,928

Zinc ore reserves remaining in the Tri-State District are estimated to be in excess of 100 million tons of 2.25% Zinc. This is equivalent to about 25 percent as much zinc as was produced during the life of the field.

GEOLOGY

The geology of the district has been discussed by numerous authors (1, 2, 3, 5, 6, 7, 10, 13, 18, 21, 22, 23, 25, 26, 27). Since most of the ore occurred in the Boone Formation of Lower Mississippian age this report is confined to the Boone and younger formations.

The Boone Formation is composed of limestone, dolomite and chert. Massive chert, one or more oolitic beds and numerous chert nodule beds are present. In the western portion of the district the Boone is overlain by Chesterian rocks and Cherokee Group rocks. The Cherokee Group Formations consist primarily of alternating terrestrial, fine-grained sandstones, shale and thin coal seams. In the eastern area, namely Galena, Joplin and Webb City, the Cherokee occurs only as scattered outliers--mainly in depressions in the old eroded surface of the Boone. In some places, as much as 100 feet of the Boone has been removed by erosion.

In the western region, a major unconformity exists between the Cherokee Group shale and the underlying Boone. In some cases the formations are roughly conformable and in other areas the Cherokee is nearly horizontal while the underlying Boone has been flexed to a marked degree. The surface topography of the Boone was developed by erosion and solution before deposition of the Cherokee and by slumping due to metamorphism and solution of the underlying Boone limestone beds after deposition of the Cherokee. Cherokee shale has been found in disturbed areas as much as 300 feet below the top of Boone.

The Boone Formation has numerous identifiable and mappable units or beds which have been designated from top to bottom as beds "B" through "R". Beds B, C, D, F, I, and Q are essentially barren. Beds E, G, and H were important lead sulfide zones. Beds J, K, and L showed mineralization in highly shattered zones. The M bed was the most important bed in the Picher area, mineralization of the B & P beds was sporadic and the "sheet ground ore" was in the O bed. Ore was produced from the R bed in the Shoal Creek area south of Joplin. Most of the beds above the M bed have been removed by erosion in the Webb City-Carterville area.

The ore was generally confined to the thinner bedded strata, and ore bodies were usually less than 30 feet thick. However, in some cases, deformation extended throughout the thick massive beds as well as the thin-bedded formations, and ore zones 80 to 100 feet in thickness were developed. Mining of these deposits resulted in rooms as much as 100 feet in height. Roof failure following scavenging and pillar robbing resulted in surface subsidence.

In the Picher field the Boone Formation is overlain by 100 to 200 feet of Cherokee Group shale and limestone and the mining depth varied from 100 to 400 feet. Whereas in the Galena, Kansas and in the Missouri areas, the mining depths varied from grass roots to 300 feet.

MINING

(References 2, 3, 8, 20, 28, 29)

Early mining in Missouri was done mostly on small plots or lots from 100 x 200 feet to 200 x 200 feet. The mineral rights belonged to the land owner who seldom was the actual operator of the land. Mine operators paid a cash rental or a royalty of 15-25 percent of the clean ore taken from the mine. Sub-leasing of all, or a part of a lot was common, and a mining lease was forfeited to the owner if no work was done on the lease for more than 15 days.

In Missouri, the state law required that there be two shafts for every mine. Consequently, on reaching the ore a drift was started to meet another existing shaft or a new shaft was sunk generally not to exceed 300 feet from the first. In addition much of the prospecting, prior to 1900, was done by means of hand dug shafts since prospect drilling had not yet been developed.

Mining activities in the Galena area of Kansas was similar to the early mining in the Joplin-Webb City areas of Missouri. Small mining lots, which were mined by individual miners or groups of miners, resulted in hundreds of shafts. When ore was discovered, drifts were run with little regard to any long-range, overall mine plan. In most cases, there were no maps made of the underground mine workings. Where ore zones were thick, the ore was worked from the upper portion of the ore down to the base of the ore to a depth at which water became too much of a problem. Water infiltration was a problem at an early stage of mining because of the large number of natural openings, open shafts and collapse areas. Mines were temporarily abandoned during mining until pumping facilities were installed by the landowners and pumping costs assessed against the individual leases. Acid mine water was reported in the early reports.

Surface subsidence over mine workings began at an early stage of the mining activities. Mining magazines and news items noted these problems before the turn of the century. Carl Henrich, in a talk to the annual meeting of the American Institute of Mining Engineers in 1892, state that "--the upper portion of an ore deposit, drained to a certain depth, is worked out as to remove the necessary support of the roof, which cave in, thus making it difficult or impossible to extract the lower and generally richest portion of the ore deposit buried under the cave. Such caves are numerous around Webb City." "--the thinner the limestone roof and the larger and richer the ore body recklessly excavated, the earlier will the mine cave in--." "--the mine

tailings were stacked in huge piles over the already over-strained roof of the mine which became increasingly more unstable as the stopes became longer and wider."

SURFACE MINING

(References 12, 32)

In several cases, ore extended to the surface and was mined by open pit methods. Early surface mining activities started after collapse of the underground operations. Seven of these abandoned open pits remain in Missouri, the Oronogo Circle mine and the Sucker Flats Mine being examples. Six open pit mines are evidenced in the Galena area and two open pit mines were reported in Oklahoma, one at Douthat and one near Lincolnville.

WATER

Water enters the subsurface through open mine shafts, and through fractured ground, especially in subsidence areas. Examples have been noted where large quantities of surface water drain directly into open mine shafts. Runoff waters from mine tailings piles and water percolating through mineralized formations can dissolve heavy metals. Mine waters have been shown to contain varying amounts of metals in solution. Acid mine water outfalls have been recorded in each of the Tri-State District States. There has been no attempt to predict how much of the inflow remains in the subsurface, how far it might travel, or the distribution and concentration of the metals in solution.

OPEN SHAFTS AND SUBSIDENCE

In the report by McFarland and Brown (17), it has been pointed out that over 7500 prospects and 2033 shafts had been sunk in the area covered by the four 7 1/2-minute quadrangles in the Missouri portion of the study area. Of this total of over 9000 mine openings, only 323 remained open at the time of their study. McCauley et al. (10) reported that there were 377 open shafts in the Galena field - mostly within a 6 square mile area which includes the city of Galena.

In the Baxter Springs-Picher area McCauley et al and Luza (14) report that over 630 open shafts were present at the time of their study. Over 90 percent of these shafts have collapsed because shaft timbers had been removed or had deteriorated. Those shafts through the Cherokee Group strata, have enlarged to create a surface opening in excess of 30 feet in diameter. In some cases the shaft openings have expanded to as much as 100 feet in diameter.

Most of the open shafts in the Galena area and in Missouri were in solid rock to near surface and as a result do not present as much of a problem as do many of the collapsed open shafts in the western portion of the district, namely Baxter Springs and Picher. In addition, the shafts in Missouri and Galena are not as deep as those in the Baxter Springs-Picher area.

Over 500 subsidence features were noted in the Tri-State District. Of

these 124 are located in Missouri, 307 are in Kansas and 82 are in Oklahoma. The largest collapse feature is located in the Kansas portion of the Picher field and covers approximately 7 acres and is approximately 100 feet deep. The largest in Oklahoma covers approximately 4 acres. The depth of this subsidence is not known since the water level is near the surface of the surrounding ground.

SHAFT CLOSURES

Methods for closing abandoned mine shafts are described in "Inactive and Abandoned Underground Mines" (31) prepared for the U.S. Environmental Protection Agency (EPA), and in a publication by the National Coal Board of Great Britain entitled "The Treatment of Disused Mine Shafts and Adits" (30). Van Dyke has described the use of an inverted cone to plug coal mine shafts. Most of the methods described in the above mentioned reports were designed to seal abandoned shafts from water infiltration. In the Tri-State District most of the abandoned mines are already filled or partially filled with water.

Approximately 90 percent of the prospect and production shafts in the area have been closed. Backfilling of the shallow mines was probably the principal method of closure. However, there are existing examples of closures by timber caps, steel plates, concrete slabs, railroad rail gratings, and concrete cubes. From time to time timber shaft caps have failed and shafts reopen. Examples of these reopenings, particularly in urban areas, have been documented by McFarland and Brown.

In a project to demonstrate a new approach to closing abandoned mine shafts in the Galena area, the U.S. Bureau of Mines designed and had constructed 11 pyramid shaped steel forms with bases of from 8 to 12 feet square (4). These forms were then placed point down, into the open shafts and filled with reinforced concrete. The elevation of these plugs has been established and monitored for several years to determine the degree of settling, if any. No appreciable movement of the plugs was noted after two years. Monitoring of these shaft closure markers is continuing.

During the Bureau of Mines Demonstration Project two shafts were closed by means of reinforced concrete caps and one shaft was closed by backfilling. Approximately 145 yds.³ of ungraded fill was used to backfill the latter shaft to the surface. This backfill was stable for about 18 months before substantial settling was noted which would require about 125 yds.³ additional fill to restore to surface. This failure probably resulted from the failure of a temporary bridge which had developed during the backfilling or to a bridge that had existed prior to backfilling. No effort had been made to remove trash from the shaft prior to backfilling or to determine whether there was pre-existing bridging.

Backfilling of the shallow shafts is probably the most practical way to eliminate the safety hazards of open shafts. However, backfilling of the deeper shafts should be done with graded material and particular attention is required to avoid bridging of the shaft. Backfilling of the deeper shafts can require large amounts of fill material, particularly where large mine openings exist at the base of the shafts. For instance a 90 foot high opening at the base of a shaft can require up to 67,000 yds.³ of fill material to reach the base of the shaft.

SELECTED REFERENCES

1. D. C. BROCKIE, E. H. HARE, P. R. DINGESS, "The Geology and Ore Deposits of the Tri-State District of Missouri, Kansas, and Oklahoma", Chapter 20 in Ore Deposits of The United States, 1933-67, 1, Am. Inst. Mining, Metall., and Petr. Engr. (AIME), 1968, 400-430 pp.
- ✓ 2. F. CLERC, "The Ore Deposits fo the Joplin Region, Mo.," AIME Trans., 38, (1907), 320-343 pp.
3. W. R. CRANE, "Methods of Prospecting, Mining and Milling in the Kansas Lead and Zinc District," Kansas Geol. Survey, 8, 1901, 177-387 pp.
4. W. DRESSEL and J. VOLOSIN, "Inverted Pyramid Shaped Plugs for Closing Abandoned Mine Shafts-Galena, Ks.", Demonstration Project, U.S. Bureau of Mines, IC 8998, 1985, 14 p.
- ✓ 5. G. M. FOWLER and J. P. LYDEN, "The Ore Deposits of the Tri-State District," AIME Trans., 102, (1932), 206-251 pp.
6. G. M. FOWLER, "Ore Deposits in the Tri-State Zinc and Lead District," Ore Deposits as Related to Structural Features, ed. by W. A. Newhouse; Princeton Univ. Press, 1942, 206-211 pp.
7. G. M. FOWLER, "Tri-State Geology", Eng. & Min. J., 144, no. 11, Nov. 1943, 72-76 pp.
8. G. M. FOWLER, R. E. ILLIDGE, and B. M. O'HARA, "Developing, Milling, and Smelting the Ores in the Tri-State (Missouri-Kansas-Oklahoma) District," AIME Mining Technology, 7, no. 4, July, 1943, 115 p. (Tech. Pub. No. 1582).
9. A. M. GIBSON, "Wilderness Bonanza--The Tri-State District of Missouri, Kansas, and Oklahoma," Univ. of Okla. Press, Norman, OK., 1972, 362 p.
10. E. HAWORTH, "History of Geography, Geology, and Metallurgy of Galena-Joplin Lead and Zinc," Kansas Geol. Surv., 8, 1901, 177-387 pp.
- ✓ 11. C. HENRICH, "Zinc-blende Mines and Mining Near Webb City, Mo.," AIME Trans., 21, 1893, 3-25 pp.
12. R. L. HERRICK, "The Joplin Zinc District," Mines and Minerals, 28, no. 4., 1907, 145-157, (describes a cave-in of the Bradford and KC Mines at Sucker Flats, Webb City, MO.)
- ✓ 13. CHAS. KEYES, "Ozark Lead and Zinc Deposits Their Genesis, Location and Migration," AIME Trans., 40, 1909, 184-231 and 856 pp.
14. K. V. LUZA, "A Study of Stability Problems and Hazard Evaluation of the Oklahoma Portion of the Tri-State Mining Area," (contract J0100133, OK Geol. Surv. -Univ. OK), U.S. BuMines OFR 76-83, 1983, 147 p.
15. A. J. MARTIN, "Summarized Statistics of Production of Lead and Zinc in the Tri-State (Missouri-Kansas-Oklahoma) Mining District," U.S. BuMines IC 7383, 1946, 67 p.

16. J. R. MCCAULEY, L. L. BRADY, and F. W. WILSON, "A Study of Stability Problems and Hazard Evaluation of the Kansas Portion of the Tri-State Mining Area (contract J0100131, Ks Geol. Surv.-Univ. Ks), U.S. BuMines OFR 75-83, 1983, 193 p.
17. M. C. MCFARLAND and J. C. BROWN, "Study of Stability Problems and Hazard Evaluation in the Missouri Portion of the Tri-State Mining Area (contract J0100132, Mo. Dept. of Nat. Resour., Div. of Geol. and Land Surv.), U.S. BuMines OFR 97-83, 1983, 141 p.
18. E. T. MCKNIGHT and R. P. FISCHER, "Geology and Ore Deposits of the Picher Field, Oklahoma and Kansas," USGS Prof. Paper 588, 1970, 165 p.
19. J. D. NORISS, "AZn: A History of the American Zinc Company State Historical Society of Wisconsin," 1968, 244 p.
20. J. PLYN, "The Joplin District-Mines and Minerals," Feb., 1904, 329 p.
21. C. E. SIEBENTHAL, "Joplin District Folio, Missouri-Kansas," USGS Geologic Atlas Folio 148, 1907, 20 p. plus maps.
22. C. E. SIEBENTHAL, "Origin of the Zinc and Lead Deposits of the Joplin Region," USGS Bull. 606, 1915, 283 p.
23. L. C. SNIDER, "Preliminary Report of the Lead Zinc Deposit of Oklahoma," Okla. Geol. Surv. Bull. 9, 1912, 97 p. (Peoria, Quapaw and Lincolnville Area.)
24. M. W. VAN DYKE, "OSM (Office of Surface Mining) Cone Design and Installation Experience," Paper presented at the summer session of the Am. Soc. of Agricultural Eng., Montana St. Univ., June 26-29, 1983.
25. C. R. VAN HISE, "Preliminary Report-Geology of the Lead and Zinc Deposits of the Ozark Region," USGS 22nd Annual Reports, 1900-1901, 87-190 pp.
26. S. WEIDMAN, "The Miami-Picher Zinc District, OK," OK Geol. Sur. Bull. 56, 1932, 177 p.
- ✓ 27. A. WINSLOW, "Lead and Zinc Deposits of Missouri," Mo. Geol. Surv., 6, 1894 (Ch. 7 - History of Mining in Missouri) 7, (sec. 2) Part III Missouri Lead and Zinc Mines. (Ch. 14, Joplin Sub-District Mines) 541-692 pp.
28. C. A. WRIGHT, "Mining and Milling of Lead-Zinc Ores," U.S. BuMines Bull. 154, 1918, (Plates V and X show examples of subsidence).
- ✓ 29. H. I. YOUNG, "Development and Underground Mining Practice in the Joplin District," AIME Trans., 57, 1917, 671-681 pp. (includes map showing location of caved ground broken through to surface).
- 30. Treatment of Disused Mine Shafts and Adits," National Coal Board, London, 1982, 86 p.
- 31. Inactive and Abandoned Underground Mines," U.S. Environmental Protection Agency (EPA), 440/9-75-007, 1975, 338 p.

32. Review of Mining, Mining and Scientific Press, 109, Aug. 22, 1914, 305 p. (mentions that the first strip pit which had not been a previously caving underground mine was started northwest of Joplin).
33. The CLWYD Mine Cap, Technical Literature from Genie Eng. LTD. Unit 16, Garston Industrial Estate, Window Lane, Liverpool 19, United Kingdom.

OTHER SOURCES OF INFORMATION

Dan R. Stewart, Webb City, MO.

C. V. Collins, Rolla, MO.

Western Historical Manuscript Collection, Library, Univ. of Missouri, Rolla, MO.

Tri-State Mine Map Catalog, Library Archives-Missouri Southern State College, Joplin, MO.

Files of the Geological Surveys of Missouri, Kansas, and Oklahoma.

Issues of ENGINEERING AND MINING JOURNAL during the 1920's and 1930's.

Issues of MINES AND MINERALS in the early 1900's.

Issues of MINING AND SCIENTIFIC PRESS in the 1920's and early 1920's.

USGS Mineral Resource Volumes.

U.S. BuMines Bulletins, Technical Papers, Reports of Investigations, Information Circulars and War Mineral Reports.

ENVIRONMENTAL HAZARDS AND CORRECTIVE ACTIONS ASSOCIATED WITH THE TRI-STATE
LEAD AND ZINC MINING DISTRICT, KANSAS AND OKLAHOMA

Alice C. Fuerst

United States Environmental Protection Agency
Region VII
726 Minnesota Avenue
Kansas City, Kansas 66101

ABSTRACT

The lead and zinc mining in Cherokee County, Kansas, and Ottawa County, Oklahoma, has left several environmental problems which could affect the public health of residents now living in the area. Several streams have high levels of heavy metals exceeding the ambient water quality standards for the protection of aquatic life. The Mississippian aquifer, which is used as a water resource for the majority of the public water supplies in the area, is threatened by the potential migration of the contaminated mine waters. Appropriate remedial actions are being explored for the situation in the eastern portion of the district in Kansas, while corrective action in the Picher District of Oklahoma and Kansas is underway.

INTRODUCTION

The lead and zinc mining areas of Cherokee County, Kansas, and the Picher District of Ottawa County, Oklahoma, have each been listed on the U.S. Environmental Protection Agency's (EPA) National Priorities List (NPL) or "Superfund" list. The NPL is the list of the most hazardous abandoned waste sites in the nation. The Kansas portion is listed as Cherokee County and the Oklahoma portion as Tar Creek. Both of these sites were put on the list because the metal-laden acidic mine water had a potential to contaminate drinking water supplies. The mine water had already caused a large impact due to discharges into the Tar Creek, killing essentially all aquatic life.

These problems developed because of the exposure of residual metallic sulfides in the abandoned mine workings and the chat piles, to air or oxygenated water. Oxidation caused the metals to become dissolved and, therefore, mobile. This resulted in an increased acidity of the water.

Since the acidic water contained toxic levels of metals, there was concern for the potential for the water to migrate from the mine workings to those portions of the formation used for private drinking water supplies. There was a potential for the mine water to also migrate to the Roubidoux Formation, which is used for municipal water supplies in the area. This migration would occur through natural fractures in the bedrock and through abandoned deep water wells, exploratory holes, and wells with faulty casings.

CHEROKEE COUNTY - INVESTIGATION

Investigations to determine the extent of contamination and to develop appropriate cleanup alternatives are underway on the Cherokee County site by

the EPA, Region VII, Kansas City. An initial investigation in the Galena area was conducted in 1985. The investigation included the collection of water and sediment samples from the three major streams and collection of water samples from several tributaries, mine shafts, ground water discharges, and ground water wells. Air, Soil, and fish samples were also collected. All of the samples were analyzed to determine their metal content.

Surface water and sediment samples were collected from Shoal Creek, Short Creek, and Spring River. Water samples also were collected from several tributaries. As would be expected in this type of mining area, the levels of lead, zinc, and cadmium were relatively high in the sediments as compared with sediments in non-mining areas. Short Creek, which runs through the mined area, had higher concentrations of dissolved metals in the water than the other major streams. The levels of cadmium, manganese, and zinc in Short Creek exceeded criteria for the protection of aquatic life. The levels of metals in tributaries to Shoal Creek also exceeded criteria for the protection of aquatic life, although Shoal Creek samples were within acceptable levels. The maximum level of zinc detected in Spring River was above the criteria. Table 1 presents the maximum concentrations of cadmium, lead, and zinc detected in the streams and the criteria for protection of aquatic life. Storm water runoff samples collected from chat-covered areas were high in zinc as shown on Table 2.

As expected, ground water samples from mine shafts and ground water discharges showed low pH and contained relatively high levels of metals. Most of the private water wells in the Galena area were sampled. Approximately 12 out of the 70 wells contained cadmium concentrations in excess of recommended health standards. The levels of cadmium ranged from undetected to 180 micrograms per liter (ug/l); the health standard is 10 ug/l. The wells in the area are between 22-425 feet in depth. There was no apparent pattern to the location or depth of the contamination.

Soil samples were collected downwind from a former smelter location. The concentrations of metals decreased with distance from the smelter site and with depth underground. These levels were compared with levels from a 1971 investigation by the Kansas Department of Health and Environment and were found to contain lower levels of metals than the 1971 samples.

The ambient air was sampled to determine if particles blown from the chat piles and tailings ponds could present a health threat. The samples were analyzed for both metals and asbestos. The results did not show a health threat. Fish from Spring River were sampled and were found to contain levels of metals similar to levels in fish at other locations in Kansas.

CHEROKEE COUNTY - REMEDIATION

The EPA will next investigate potential remedial actions to help mitigate the pollution problem in the Galena area. The Agency will investigate methods to reduce the levels of metals entering Short Creek. These methods could include: 1) redirecting a captured stream containing good quality water so that it would flow into Short Creek, 2) recontouring portions of the mining area just north of Galena to change the runoff patterns, and 3) regrading, capping, and revegetating portions of the mining area north of Galena to reduce infiltration and generation of additional contaminants and to improve the quality of the runoff to Short Creek.

Table 1
Maximum Concentrations of Metals Detected
Surface Water

	Short Creek		Shoal Creek		Shoal Creek Watershed		Spring River		Aquatic Life Criteria	
	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Chronic	Acute
Cadmium	140	160	U	U	170	170	U	7.4	0.025	3
Lead	U	21	U	120	1700	1800	U	17.0	3.8	170
Zinc	24,000	25,000	U	250	33,000	34,000	320	540	47	320
* All values in micrograms per liter										
U = Undetected										

Table 2
STORM RUNOFF WATER QUALITY

	<u>Runoff from Chat Covered Areas</u>		<u>Runoff from Areas Not Chat Covered</u>	
	<u>Average</u>	<u>Range</u>	<u>Average</u>	<u>Range</u>
Total Lead (ug/l)	37	U-110	U	U
Dissolved Lead (ug/l)	23	U-68	U	U
Total Zinc (ug/l)	7300	2500-14000	2200	1800-2600
Dissolved Zinc (ug/l)	7100	2900-13000	1900	1800-2000
Total Cadmium (ug/l)	51	17-83	13	5-21
Dissolved Cadmium (ug/l)	51	20-79	13	6.3-19
Acidity (mg/l)	U	U	U	U
Alkalinity (mg/l)	35	U-74	79	77-80

U = undetected

To assist those individuals with high levels of cadmium in their well waters, EPA installed individual filtering treatment units on those wells. The Agency will maintain the units for two years.

TAR CREEK - INVESTIGATION

Investigations of the extent of contamination and to develop cleanup options in the Picher district were completed in 1984 by the Oklahoma Water Resources Board (OWRB). They found the greatest impacts were to Tar Creek and potentially to Grand Lake and the Roubidoux Formation, both of which are major resources for drinking water. To mitigate the problems, OWRB elected to plug wells penetrating the Roubidoux and to construct diversion structures along the Tar Creek drainage basin in three areas where the surface water was captured by mine collapses.

TAR CREEK - REMEDIATION

The purpose of the well plugging program was to remove a pathway for the contaminated water to migrate to the Roubidoux Formation. The OWRB located information indicating the existence of 66 abandoned water wells and exploratory boreholes penetrating the Roubidoux in the Picher District, 26 in Kansas and 40 in Oklahoma. These wells intersected the Roubidoux at approximately 900-1200 feet.

Plugging operations began in 1985. Before a well could be plugged, each had to be drilled out to remove debris. Before plugging, the U.S. Geological Survey ran a set of geophysical logs on several of the wells. The wells were plugged with an acid resistant cement. Only 47 of the original 66 wells were actually plugged. The other 19 wells were not plugged by OWRB because the wells could not be located, did not penetrate the Roubidoux, were plugged by others, were currently in use or other complications were discovered in the field. Seventeen additional wells were located during and following the initial plugging and were plugged during the summer of 1986.

The OWRB's investigation showed that 75 percent of the surface water entering the mines was through three inflow locations at mine collapses. The surface water diversion program was designed to reroute the streams that are captured by mine collapses back to the major stream channel. Two of these structures will be in Kansas and one in Oklahoma. The diversions will be accomplished by a construction of dikes around subsidences and excavating new channels. Construction on the diversion structures began in the summer of 1986.

The OWRB intends to monitor the results of the plugging and diversion programs for three years to evaluate the effectiveness. At that time, it may be determined that additional remedial work is needed.

SUMMARY

The EPA - Kansas City and the OWRB have conducted investigations in the Tri-State Lead and Zinc Mining District in Kansas and Oklahoma to determine the extent of contamination and to develop remedial actions to correct the problems. Several surface water streams have been found to contain high levels of toxic metals. The shallow ground water in the Galena area also shows concentrations of toxic metals. There is a potential for the acidic mine water to migrate to the Roubidoux Formation, which is used as the primary drinking water resource in the area. The OWRB has plugged several wells that penetrate the Roubidoux Formation and is rerouting the surface water at three locations where the streams flow into mine collapses.

REFERENCES

EPA, 1986, Phase I Remedial Investigation Report, Cherokee County-Galena Subsite, 135 p.

EPA, 1984, Tar Creek - Record of Decision.

Irwin, J. C., 1971, Survey of Environmental Contaminants Near Galena, Kansas: Air Quality and Occupational Health Section, Kansas Department of Health and Environment, 63 p.

EFFECTS OF ABANDONED LEAD AND ZINC MINES AND TAILINGS PILES ON WATER QUALITY IN THE JOPLIN AREA, MISSOURI*

James H. Barks

U.S. Geological Survey
Rolla, Missouri

INTRODUCTION

Commercial development of the mineral resources of southwestern Missouri began about 1850 and spread into southeastern Kansas and northeastern Oklahoma, forming the Tri-State Mining District with Joplin as the urban center (fig. 1). The value of the Tri-State Mineral production from 1850 to 1950 exceeded one billion dollars, and until 1945 the region was the world's leading producer of lead and zinc concentrates, accounting for one-half of the zinc and one-tenth of the lead produced in the United States (Gibson, 1972¹). By 1950 most of the rich ores had been extracted, and mining and milling operations declined during the 1950's and ceased in the 1960's.

The sulfide minerals, mainly galena and sphalerite, were mined from cherty limestones at depths of 25 to 75 m (meters). Crude ores were brought from the mines to the surface where they were milled into lead and zinc concentrates. Barren rock was discarded in piles while the ore-bearing rock was crushed and ground into fine gravel. The minerals were separated from the rock by a jigging process and the tailings were skimmed off and discarded in large piles. Ground water flooding of the mines was controlled by constant pumping. When pumpage declined in the 1950's and 1960's the abandoned mine drifts and shafts filled with water. At present (1977) numerous tailings piles and flooded mines remain as visible evidence of the mining era and as a threat to the quality of ground and surface waters of the area.

In 1976 the U.S. Geological Survey in cooperation with the Ozark Gateway Council of Governments made a study of the effects of the mines and tailings piles on water quality in the Missouri part of the Tri-State District. The study area covers approximately the southwestern quarter of Jasper County, an area of about 725 km² (square kilometers), and is bounded by long 94°15'W., and the Missouri-Kansas state line, and lat 37°15'N., and the Jasper-Newton County line.

The principal objective of this study was to evaluate the extent to which abandoned mines and tailings piles are affecting the chemical quality of ground and surface waters in the Joplin area, with emphasis on Center Creek. The approach involved characterizing the quality and determining the movement of mine water and seepage and runoff from tailings areas. It also involved delineating specific reaches of streams that are affected and when possible, separating the effects of mine-water discharge from those of tailings area discharge.

*Reproduced with permission from the Society of Mining Engineers of AIME Fall Meeting, St. Louis, Missouri, 1977 (Preprint No. 77-AG-308).

SUMMARY AND CONCLUSIONS

Dissolved zinc concentrations averaged 9,400 ug/L (micrograms per liter) in water from abandoned lead and zinc mines, some of which discharge at the surface. Contamination of the shallow aquifer by the highly mineralized mine water is limited to the immediate mining area. The quality of water in the deep aquifer is generally excellent and unaffected by mine water.

Dissolved zinc concentrations averaged 16,000 ug/L in runoff from tailings areas. However, during a summer storm, runoff from a 0.028 km² tailings area contained maximum dissolved zinc, lead, and cadmium concentrations of 200,000; 400; and 1,400 ug/L, respectively.

Mine-water discharges increase dissolved zinc concentrations in receiving streams from a background of about 40 ug/L to about 500 ug/L during periods of low flow. The higher concentrations are sustained during high flow by runoff from the tailings areas. Deposition of tailings on stream bottoms increases zinc concentrations in bottom material from a background of about 100 ug/g (micrograms per gram) to about 2,500 ug/g and increases lead concentrations in bottom material from about 20 ug/g to about 450 ug/g.

Results of this study indicate the continuing need to control metal-mining wastes after mining has ceased, as well as during active mining.

GROUND WATER

The shallow aquifer consists of cherty limestone of Mississippian age and the deep aquifer consists of cherty dolomite and sandstone of Ordovician and Cambrian age. The shallow and deep aquifers are separated by relatively impermeable silty limestone and shale of Mississippian and Devonian age. The shallow aquifer reaches the surface at places and extends as deep as 150 m. The deep aquifer is reached at a minimum depth of about 100 m and extends as deep as 550 m.

Water-level measurements in approximately 200 wells and mine shafts that bottom in the shallow aquifer show the water table is 10 to 30 m below land surface at higher elevations (ground-water recharge areas) and near the land surface at lower elevations (ground-water discharge areas). A few mine shafts have spring-like discharges of mine water. Ground-water divides generally correspond to topographic divides. The movement of ground water is from the divide areas to the streams.

Dissolved-solids concentrations in water from the mine shafts are generally greater than 1,000 mg/L (milligrams per liter). In ground-water recharge areas downward movement prevents water in drifts from circulating up into mine shafts (fig. 2), and water in these shafts contains less than 500 mg/L dissolved solids. Conversely, in ground-water discharge areas upward water movement causes water in the drifts to circulate up through the shafts. This phenomenon is further illustrated by specific conductance, pH, temperature, and dissolved oxygen profiles that represent average characteristics for seven mines in recharge areas and three mines in discharge areas (fig. 3).

Major constituents in water from 14 mines, 21 shallow wells, and 14 deep wells are summarized in Figure 4. Calcium and sulfate account for most of the

increased mineralization of the mine water, but zinc which averaged 9,400 ug/L is very significant from the standpoint of pollution. Other metals are generally low in concentration in the mine water because surrounding limestone rocks neutralize the mine water to a pH of greater than 6.0. Results of the shallow well sampling indicate that although wells located in or very near mines may be seriously affected by the mine water, there does not appear to be widespread dispersion of the highly mineralized mine water in the shallow aquifer.

Water in the deep aquifer is a calcium magnesium bicarbonate type and it can be distinguished from water in the shallow aquifer by its lower mineral content and lower calcium magnesium (Ca:Mg) ratio. The average Ca:Mg ratio (calcium and magnesium expressed in milliequivalents) is 23 for water in the mines, 23 for water in the shallow wells, and 1.7 for water in the deep wells. The lower ratio for water in the deep aquifer is indicative of the higher magnesium content of the dolomitic rocks. The deep aquifer is separated from the shallow aquifer by confining beds, but faults, fracture openings, or poorly constructed wells can connect the aquifers resulting in increased downward leakage. Evidence that this may be happening can be found in the Webb City area where a municipal well near a mine was abandoned in 1972 because of high mineralization of the water. In general, however, quality of water in the deep aquifer appears to be excellent and relatively unaffected by mine water.

TAILINGS AREA RUNOFF

There are about 12 km² of tailings amounting to about 41 million m³ (cubic meters) in the Joplin area. About two-thirds of these are in the Center Creek basin. The distribution and size of tailings piles on the surface generally correspond to the distribution and size of mines beneath the surface. However, some of the ore was removed from the area for processing and some of the tailings have been removed and used for road surfacing and railroad ballast or ground into sand for sand blasting.

The greatest concentration of tailings piles is in the Oronogo-Duenweg mining belt which is about 3.2 km (kilometers) wide and extends from Oronogo to Duenweg, a distance of about 16 km. Outside the Oronogo-Duenweg belt the tailings piles are generally scattered and intermixed with woodlands and farmlands. Drainage from the Oronogo-Duenweg belt is primarily to Center Creek by way of Stoutt and Mineral Branches, which are both dry except during periods of heavy rainfall.

In eight reconnaissance samples of tailings seepage and runoff, dissolved-solids concentrations averaged 414 mg/L, compared to 134 mg/L for Center Creek upstream from the mining area. Dissolved zinc concentrations averaged 16,000 ug/L. The pH of the tailings runoff samples averaged 6.4, but in the sample with the lowest pH (3.5) maximum concentrations of dissolved zinc (35,000 ug/L), lead (1,400 ug/L), and copper (360 ug/L) were observed. Other metals concentrations were generally low.

On June 23, 1976, between 0430 h (hours) and 1430 h, 13 cm (centimeters) of rain fell on a 0.038 km² tailings area that had been selected₃ for storm-runoff sampling. Runoff from the area increased from 0 m³/s (cubic meters per second) at 0430 h to a peak of 0.28 m³/s at 0800 h, then gradually decreased to 0.017 m³/s at 1220 h (fig. 5). Flow that occurred after 1220 h

was mainly seepage out of a 70,000 m³ tailings pile, which continued for 9 days after rainfall stopped. There was an inverse relationship between the amount of runoff and the concentration of dissolved constituents in the water as shown by the dissolved solids and discharge graphs in Figure 5. Of particular significance are the high concentrations of dissolved zinc (fig. 6) which reached a maximum of 200,000 ug/L and lead and cadmium (fig. 7) which reached maximum values of 400 and 1,400 ug/L, respectively. The water had a pH of less than 5, but soon mixed with higher pH water in Stoutt Branch and the lead and cadmium quickly precipitated. Analyses of water-suspended sediment mixtures indicate that during storm runoff nearly all of the zinc is in solution, but large amounts of lead are sorbed to suspended sediment.

EFFECTS ON STREAMS

Center Creek, which has an average flow near the mouth of about 6.8 m³/s is the largest stream in the area that is affected by mine-water discharge and tailings area runoff.

The station, Center Creek near Carterville is 30 km upstream from the mouth and is at the upstream edge of the mining area. The station, Center Creek near Smithfield is about 1.6 km upstream from the mouth and is downstream from the mining area. Dissolved zinc concentrations in water samples collected monthly from Center Creek near Carterville and bimonthly from Center Creek near Smithfield during water years 1971 to 1975, are summarized in Table 1. A water year is from October 1 to September 30. For example, the 1975 water year is from October 1, 1974 to September 30, 1975. The samples were collected during both low- and high-flow periods. During water years 1974 and 1975 dissolved zinc concentrations in water from Center Creek near Carterville were at or near background levels while dissolved zinc concentrations in water from Center Creek near Smithfield were consistently high. The higher concentrations at both sites during water years 1971 to 1973 were probably caused by pumping of mine water that eventually discharged into Center Creek upstream and downstream from Carterville. During low-flow periods the high zinc concentrations were caused by mine-water discharge, but during periods of high flow tailings area runoff was the main source. Concentrations of dissolved lead, chromium, and copper were uniformly low at both sites during the 1971 to 1975 water years.

Data from a seepage run made on Center Creek September 20-22, 1976, delineates points and reaches where baseflow gains and losses and water-quality changes occur (fig. 8). At the time the seepage run was made the flow in Center Creek was about twice the 7-day 2-year minimum discharge. Specific conductance of the water in Center Creek increased from 305 umhos/cm at 25°C (micromhos per centimeter at 25 degrees Celsius) near Fidelity to 468 umhos/cm at 25°C near Smithfield. The difference is due mainly to sudden increases caused by surface inflow from Grove Creek, Mineral Branch, and the D.C. and E. mine and by ground-water inflow along a short reach upstream from Oronogo. The reach just upstream from Oronogo is in a swampy area and is the only place where mine workings cross Center Creek. The increases in specific conductance were caused mainly by increases in calcium and sulfate that, except for Grove Creek, were accompanied by significant increases in dissolved zinc (fig. 9). Dissolved zinc increased from a background of 40 ug/L upstream from the mining area to 500 ug/L downstream. Nearly all of the increase was caused by mine-water discharges from the Sunset mine and a nearby unnamed mine into Mineral Branch at Carterville that enters Center Creek 2.4 km upstream from

Oronogo, subsurface seepage of mine water into Center Creek about 0.4 km upstream from Oronogo, and discharge from the D.C. and E. mine that enters Center Creek 0.6 km downstream from Oronogo.

During high-flow conditions the high dissolved zinc concentrations are sustained by seepage and runoff from the tailings areas that are discharged mainly through Stoutt and Mineral Branches. Total zinc concentrations were usually about 30 ug/L higher than dissolved concentrations indicating most of the zinc is in solution, but some is associated with suspended sediments. Dissolved and total lead concentrations ranged from 1 to 29 and 5 to 59 ug/L, respectively, with no apparent increase downstream from the mining area. Concentrations of zinc in the bottom material increased from a background of 100 ug/g to about 2,500 ug/g and lead in the bottom material increased from a background of 20 ug/g to about 450 ug/g (fig. 10). These 25-fold increases occurred mainly downstream from Stoutt and Mineral Branches, and appear to be due to the deposition of tailings transported by these two branches during periods of storm runoff.

It is likely that the desire to control or limit environmental degradation was not as prevalent during the Tri-State District mining era as it is today, and the technology to do so certainly was not as advanced. The "New Lead Belt" in southeast Missouri (Wixson and Jennett, 1975²) is an excellent example of how today's environmental awareness, technology, and cooperation have combined to keep production of metals at a peak and environmental damage at a minimum. Results of the Joplin area study should serve as a general reminder of the continuing need to control waste discharges from active mining, as well as after mining has ceased.

-
1. Gibson, A. M., "Wilderness Bonanza," Norman, Okla., Univ. of Oklahoma Press, 1972, 363 p.
 2. Wixson, B. G., and Jennett, J. C., "The New Lead Belt in the Forested Ozarks of Missouri," Environmental Science and Technology, 1975, pp. 1128-1133
-

Table 1.--Dissolved zinc in Center Creek

Water years	Average concentration (in micrograms per liter)	
	Carterville	Smithfield
1971-73-----	270	880
1974-75-----	31	440

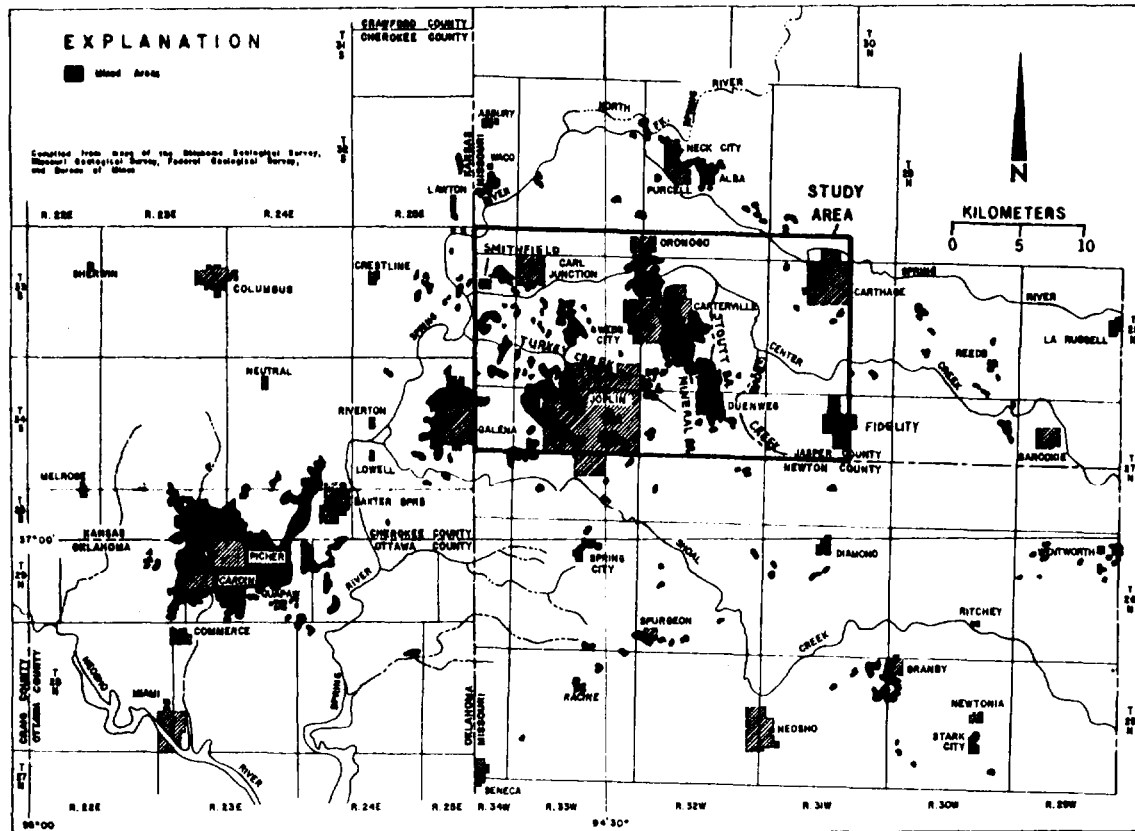


Figure 1. Principal part of the Tri-State zinc-lead district showing mined areas.

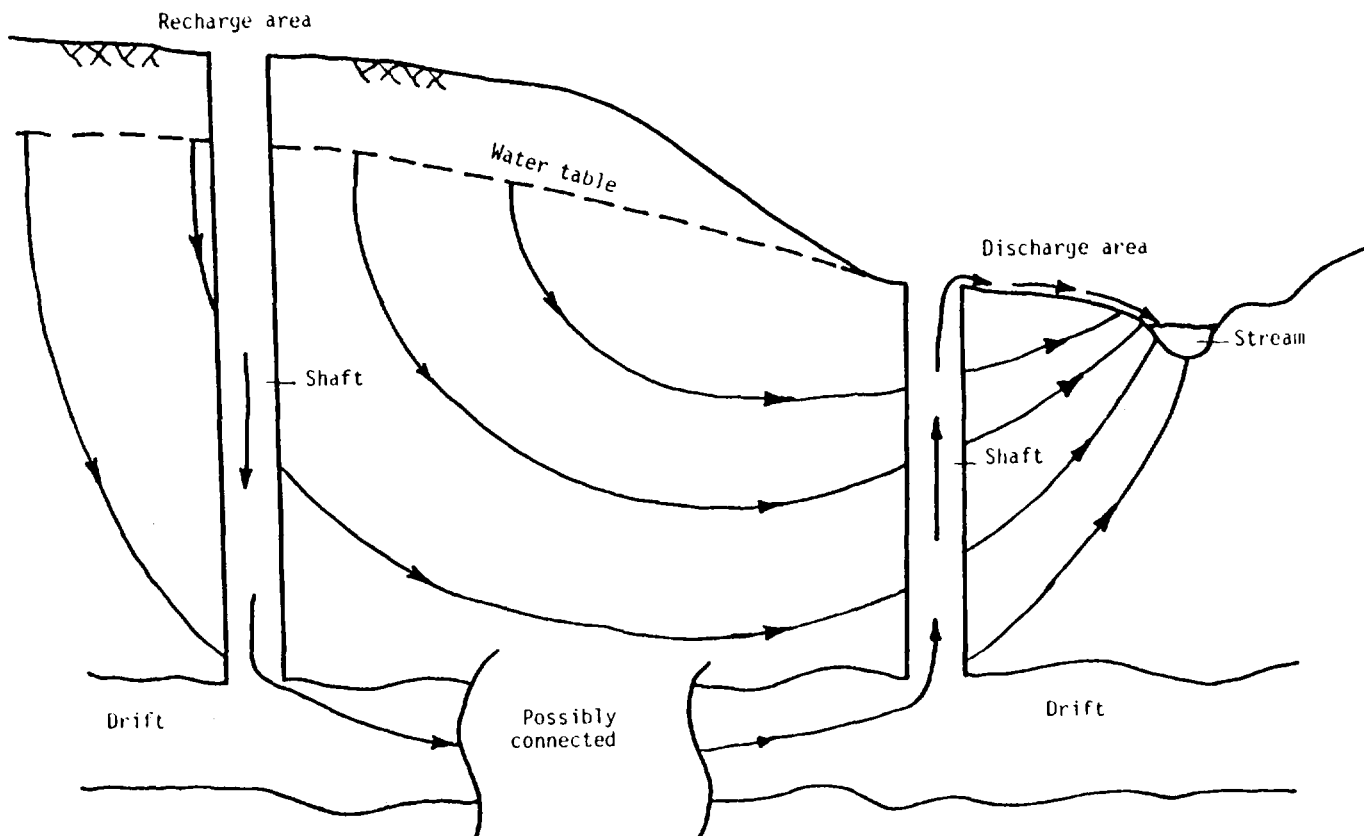


Figure 2.--Sketch showing mine-water circulation.

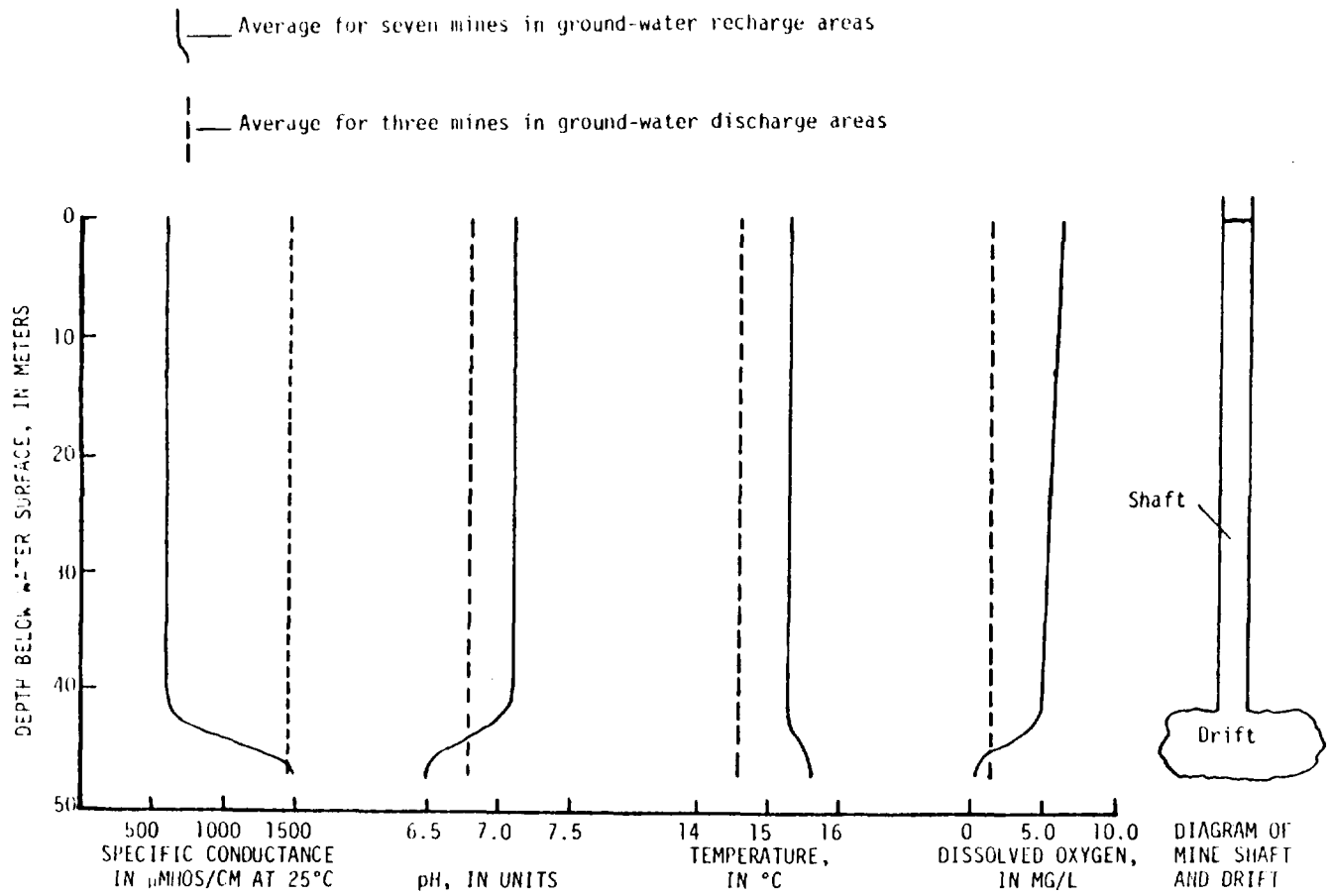


Figure 3.--Specific conductance, pH, temperature, and dissolved oxygen profiles for mines in ground-water recharge areas and ground-water discharge areas.

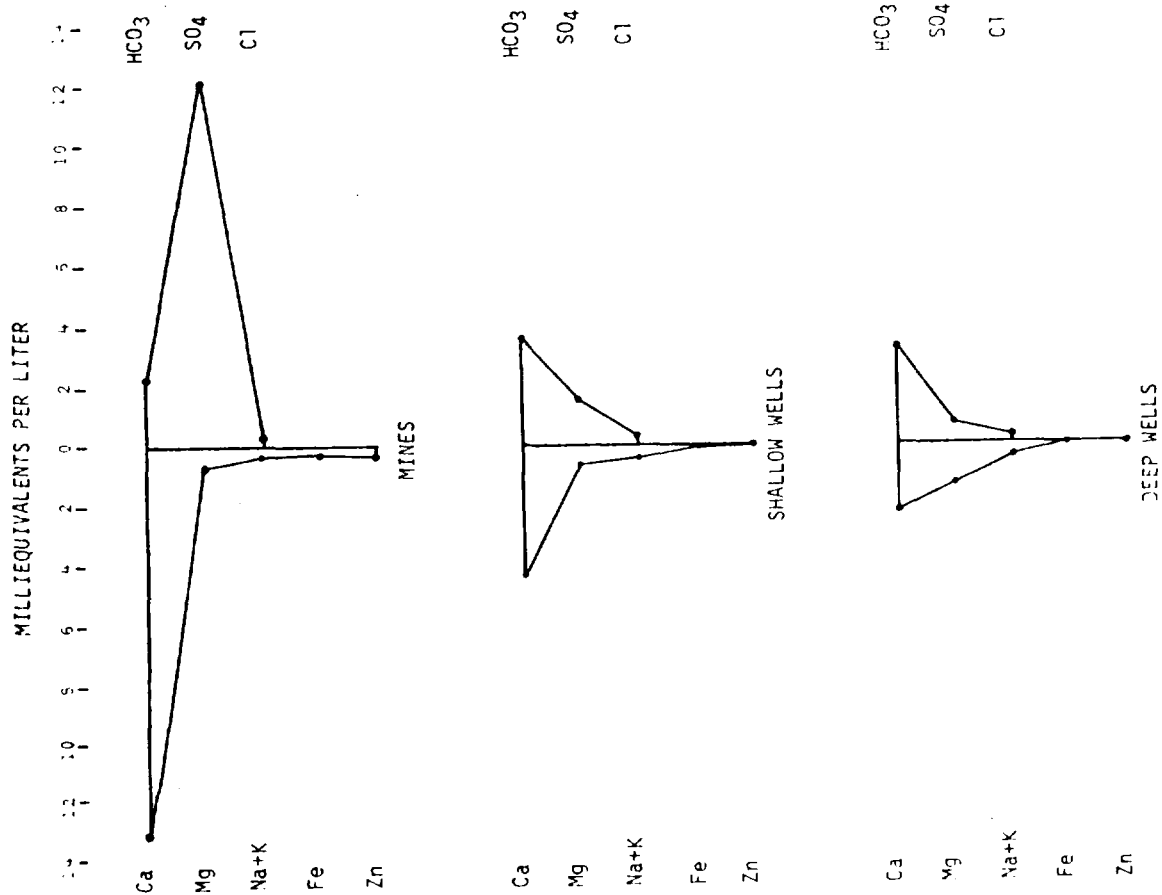


Figure 4.--Chemical character of water from mines, shallow wells, and deep wells.

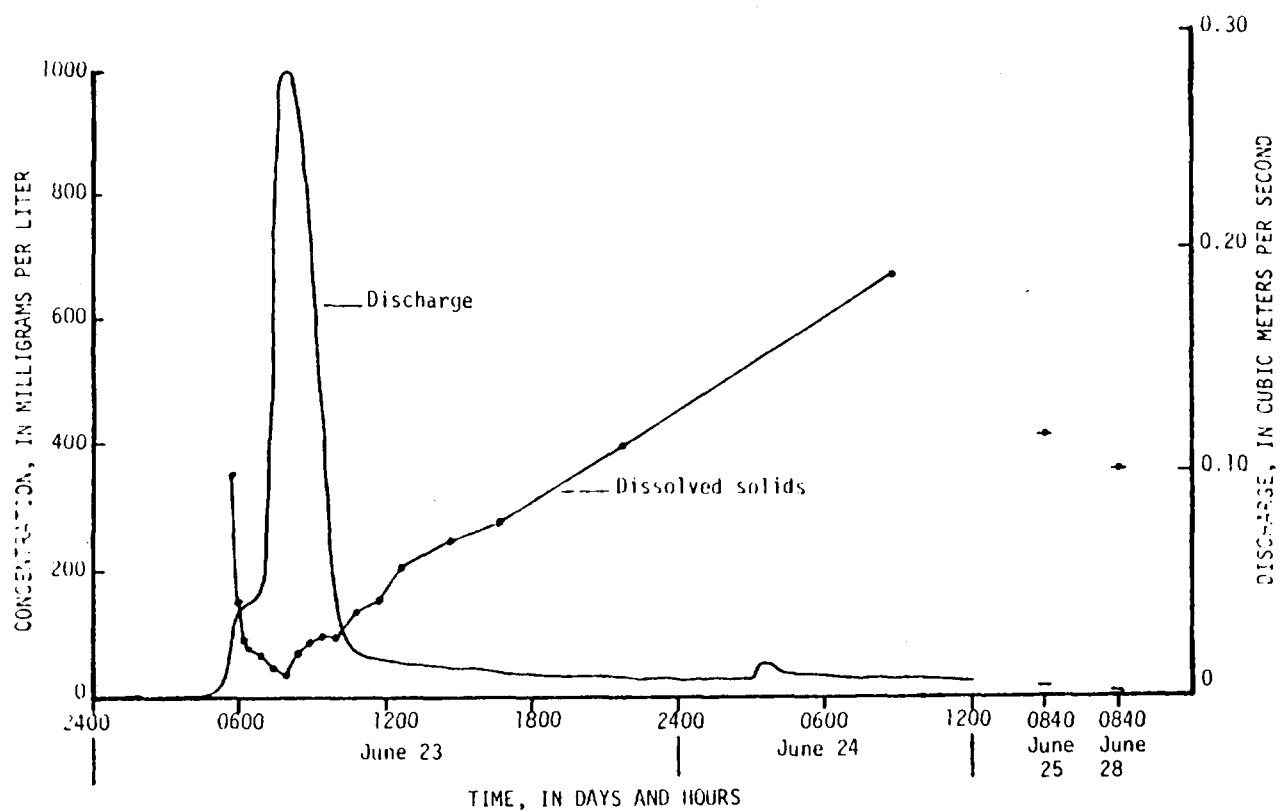


Figure 5.--Dissolved-solids concentrations in storm runoff from 0.028 square kilometer tailings area, June 23-28, 1976.

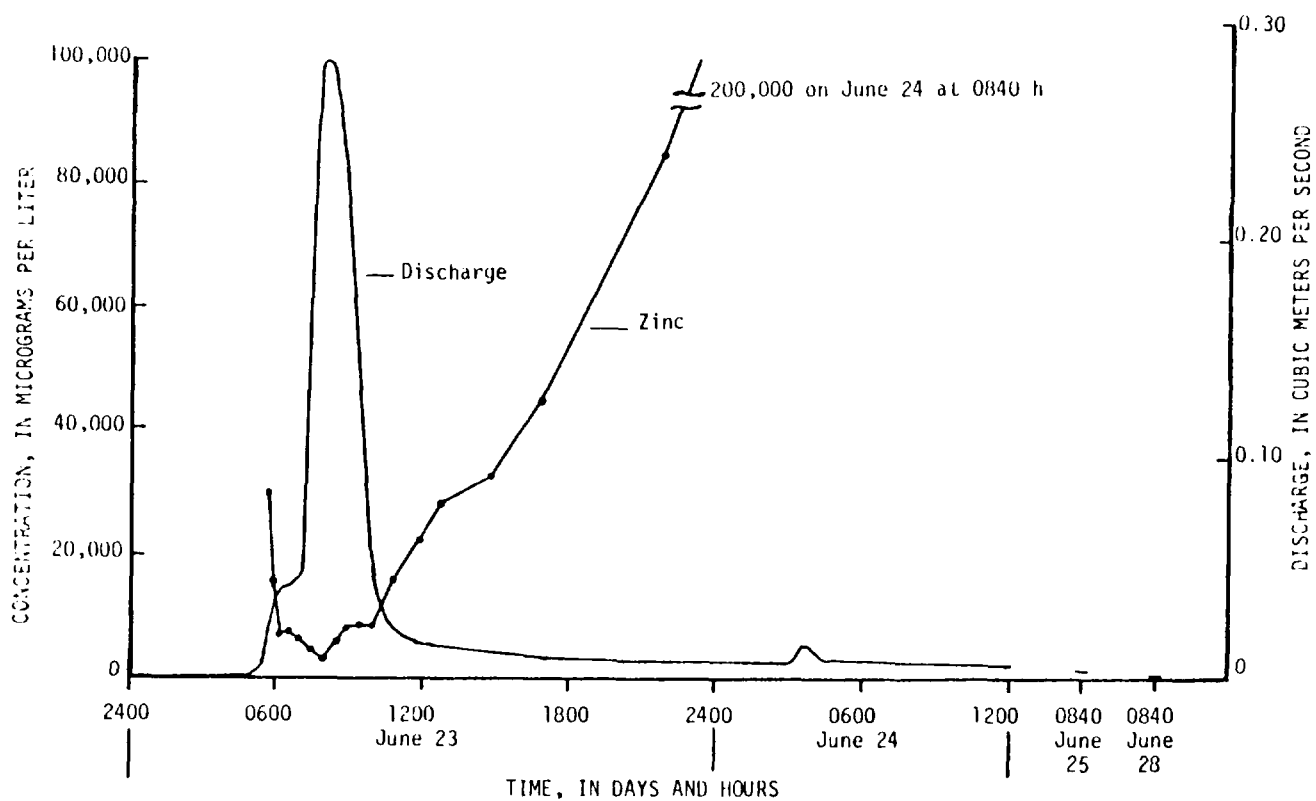


Figure 6.--Dissolved zinc concentrations in storm runoff from 0.028 square kilometer tailings area, June 23-28, 1976.

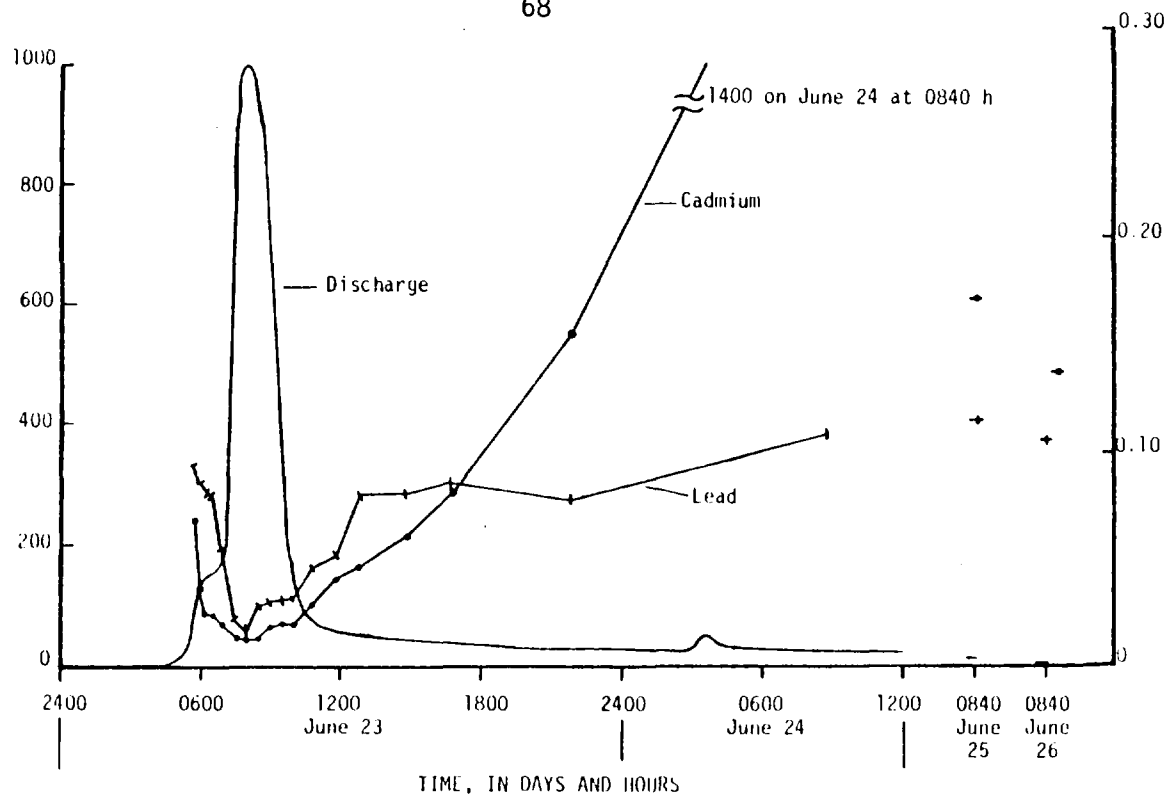


Figure 7.--Dissolved cadmium and lead concentrations in storm runoff from 0.028 square kilometer tailings area, June 23-28, 1976.

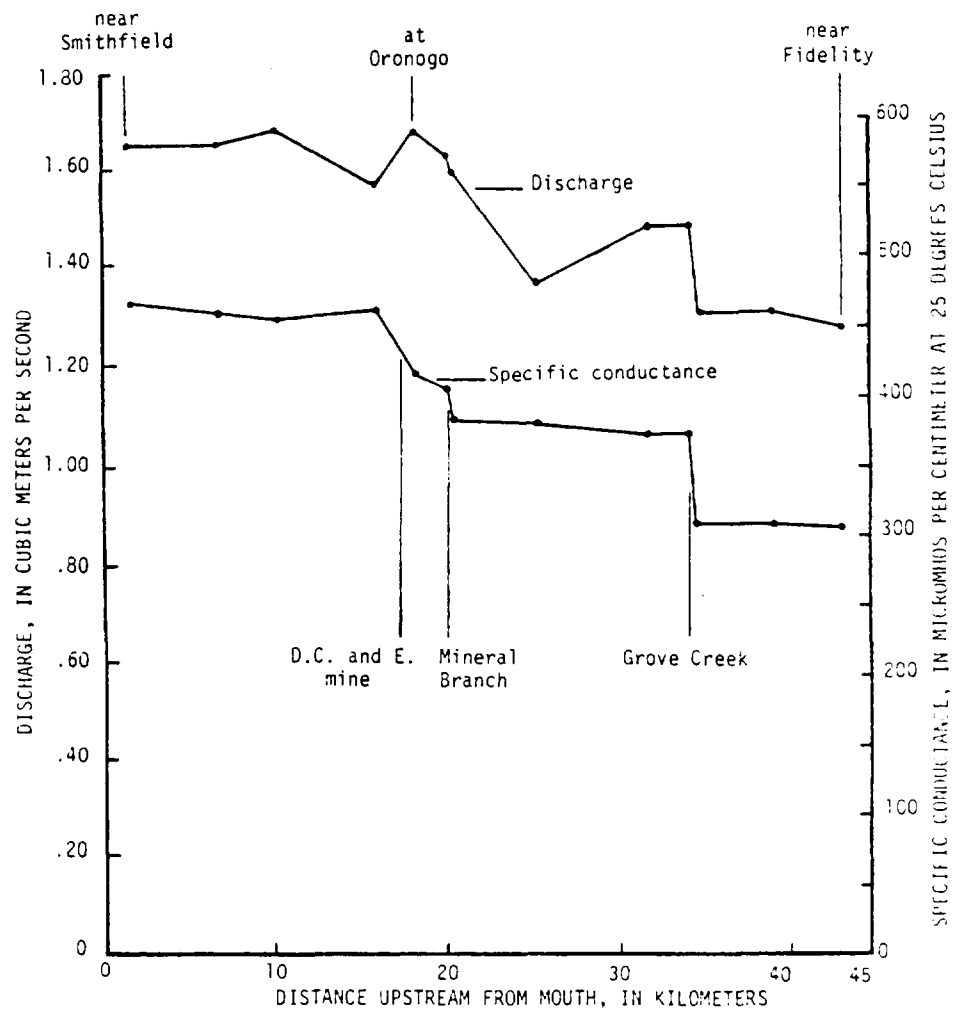


Figure 8.--Relation of discharge and specific conductance to distance upstream from mouth of Center Creek, September 20-22, 1976.

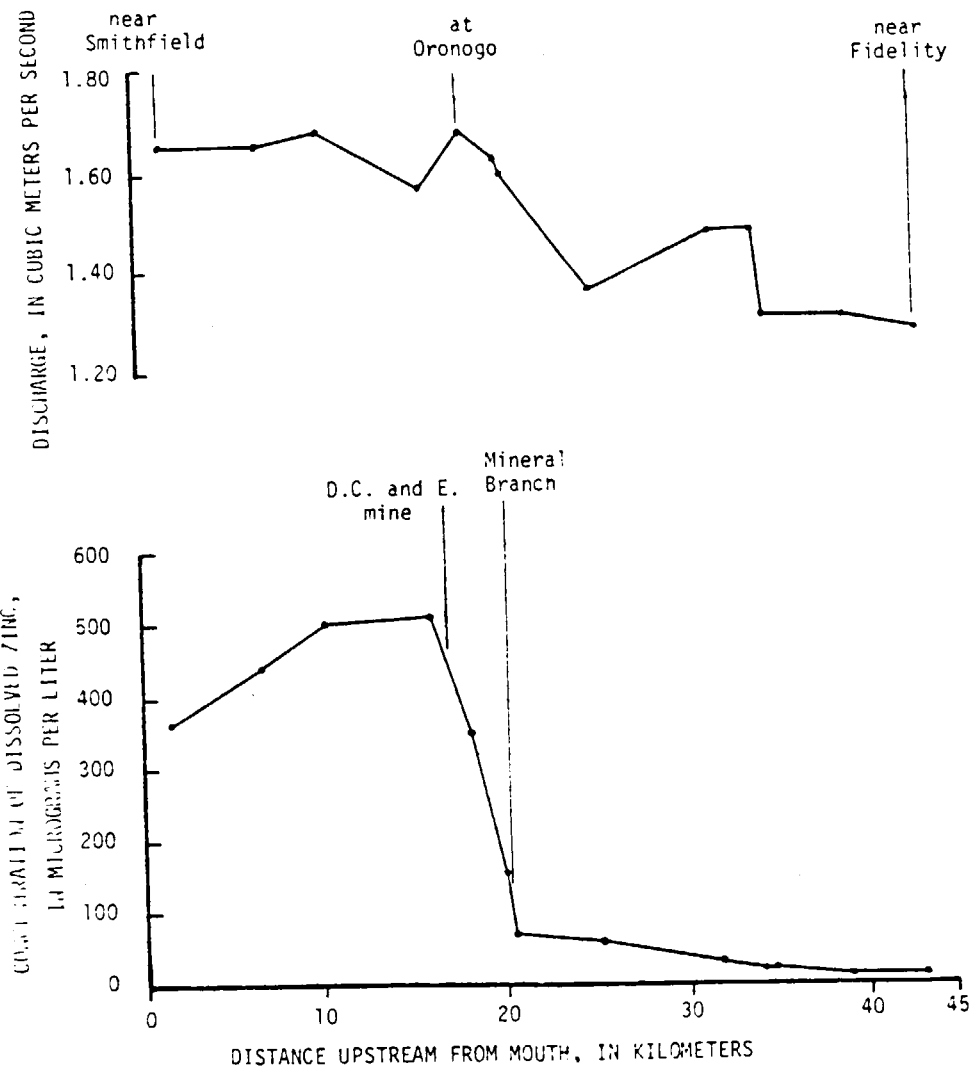


Figure 9.--Relation of dissolved zinc and discharge to distance upstream from mouth of Center Creek, September 20-22, 1976.

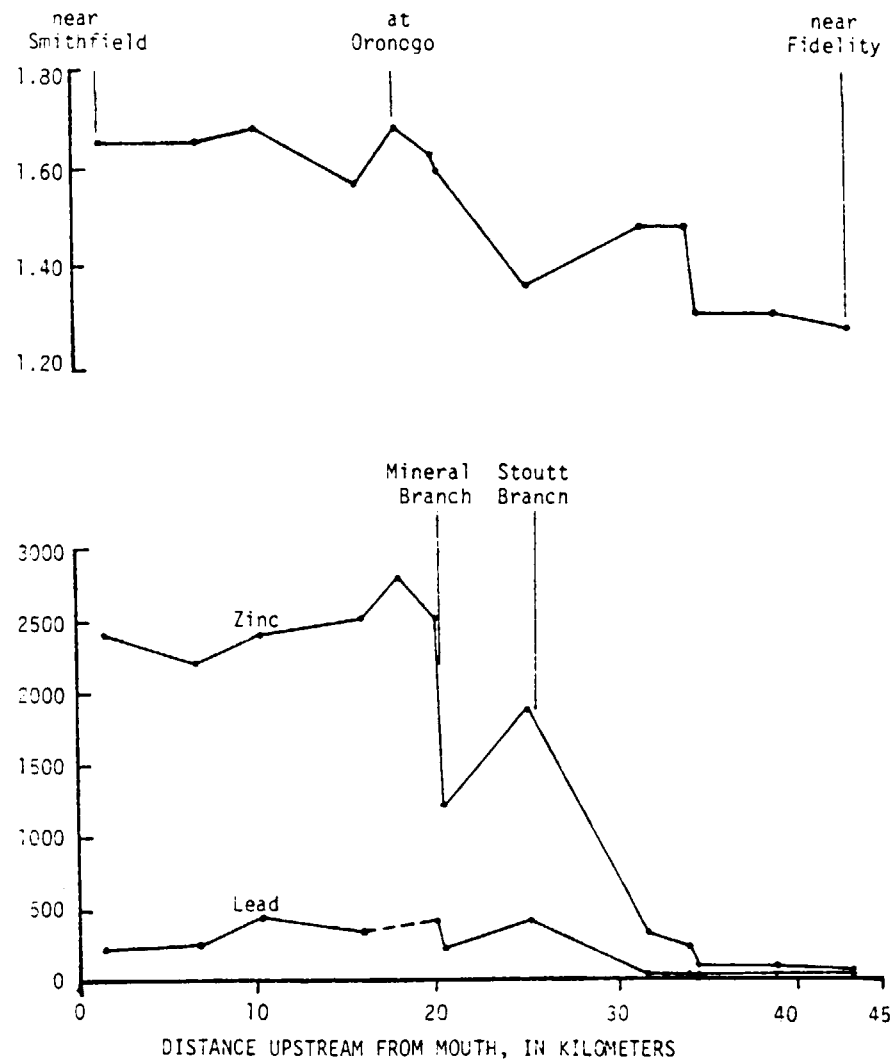


Figure 10.--Relation of zinc and lead in bottom material and discharge to distance upstream from mouth of Center Creek, September 20-22, 1976.

Results to Date of CUSMAP Studies in the Joplin Quadrangle

by Pieter Berendsen

This study was started in the fall of 1983 as a cooperative effort between the United States Geological Survey (U.S.G.S.) and the Missouri and Kansas State Geological Surveys. The objectives of the project are to develop an improved understanding of the stratigraphy, sedimentology, structure, sedimentary and basement petrology, geochemistry and mineral resource potential of the quadrangle.

To accomplish the objectives a number of tasks have to be performed by the individual organizations. Some of these tasks are nearing completion, others are in progress or still need to be started. This brief progress report describes those tasks undertaken primarily by the K.G.S. that are nearing completion or are far enough along to comment on their status.

The reasons for selecting the Joplin quadrangle as a study area are:

1. The southeastern part of the quadrangle includes most of the well-known world-class Tri-State mining district.
2. The Mississippian carbonate host rocks underlie at shallow depth the remainder of the quadrangle in the subsurface.
3. The quadrangle adjoins to the west several other quadrangles for which mineral appraisal studies have been (Rolla, Springfield) or will shortly be (Harrison) completed.
4. It will thus be possible to evaluate mineral and structural trends, stratigraphy, and environments of deposition over a much larger area. The study will be especially helpful to better correlate the geology and chemistry between the two states.

The Joplin quadrangle comprises three counties in Missouri (Vernon, Barton, Jasper), plus small areas of five surrounding counties to the east and south. In Kansas a total of nine counties (Woodson, Wilson, Montgomery, Allen, Neosho, Labette, Bourbon, Crawford, Cherokee) and small areas of three adjoining counties to the west are included in the quadrangle (Figure 1).

GEOCHEMISTRY

All geochemical analyses were carried out by U.S.G.S., using a 6-step D.C. arc optical emission spectrograph, which enabled them to semiquantitatively analyze each sample for 31 elements.

In Kansas approximately 85 drill holes were selected for geochemical studies. Except for six drill holes for which core was available, all other samples consisted of drill cuttings (Figure 3). The distribution of the drill holes is quite uneven. Not much data is available for the northeastern and south-central part of the Kansas portion of the quadrangle. The lithology of the samples was described to aid in the determination of the stratigraphic units present. Insoluble residues were prepared and described, and subsequently crushed for chemical analysis. Whenever the available material permitted, samples of ten-foot intervals were taken. A

total of approximately 5000 samples were analyzed and are being evaluated in much the same manner as has been done for the completed quadrangles. Preliminary geochemical logs and maps showing the distribution and concentration of certain elements (e.g., As, Zn, Pb, Ca, Ni, Co, Mo, Ag) above a threshold over a given stratigraphic interval have been prepared by R. Erickson of the U.S.G.S. The Kansas Geological Survey (K.G.S.) is in the process of entering the data in a computer file for further statistical studies.

GEOLOGIC MAPPING

A geologic map of at a scale of 1:250,000 of the Kansas portion of area is being prepared by F. Wilson and J. McCauley of the K.G.S. Geologic maps of individual counties (Allen, Neosho, Labette, Montgomery, Cherokee) exist in the K.G.S. files.

The geologic information from the county maps augmented with information from the state geologic map for those counties for which no geologic maps exist, has been digitized and a preliminary composite map has been prepared. County line correlation problems exist because selected mappable units and the scale at which the maps were prepared differed from county to county. Remote sensing techniques and field checking are used to solve these problems. Additional correlation problems exist across the state line between Missouri and Kansas. These mainly resulted from the choice of mappable units and should be easily resolved.

The finished 1 X 2 degree geologic quadrangle map will serve as a prototype of other geologic maps planned for the state of Kansas.

GEOPHYSICS

A preliminary aeromagnetic map (figure 2) has been prepared by the K.G.S. under the direction of H. Yarger. The data set from which the map is prepared consists of 1/2-mile spaced N-S flight lines providing about 13 reading per mile. E-W tie lines are spaced 10 miles apart.

Because of the low altitude at which the survey was flown and the data point density, a number of anomalies believed to be associated with cultural features are observed on individual flight lines. In this preliminary version large anomalies that show up on only one flight line were discarded. Additional field checking will be necessary to ascertain that no legitimate anomalies are omitted. The map shows a lot more detail than the state-wide version published by Yarger in 1981. Additional unknown, or better defined anomalies and linear, possibly structural, trends will certainly help in interpreting the geology in the area.

A preliminary gravity map (figure 3) has also been prepared. In the Kansas portion of the quadrangle 1 mile spaced data points were acquired for the project. Existing Defense Mapping Agency data points with a spacing of approximately 5 miles were utilized for the Missouri portion of the quadrangle. Interesting northeasterly and northwesterly structural trends and well-defined anomalies are shown.

Seismic reflection studies have been carried out by R. Knapp in the area of the Silver City Dome, Woodson County. The intrusive rock was formerly called a mica-peridotite, but recent studies have shown it to be a lamproite. These are the kinds of rock in which the latest diamond finds were made in western Australia. The lamproite was interpreted to have come up along a fault on the northern side of the ellipsoidal-shaped depression known as Silver City dome.

Preliminary interpretation of the seismic data shows the structure as a whole to be much more complex and possibly be a volcanic feature. Faulting along the northern and southern rims of the depression is indicated as well as faulting and slight doming near the center, indicating that lamproite was injected centrally in the dome.

Rose Dome located about 4 miles to the northeast is a similar features. A strong northeast linear trend connects in two.

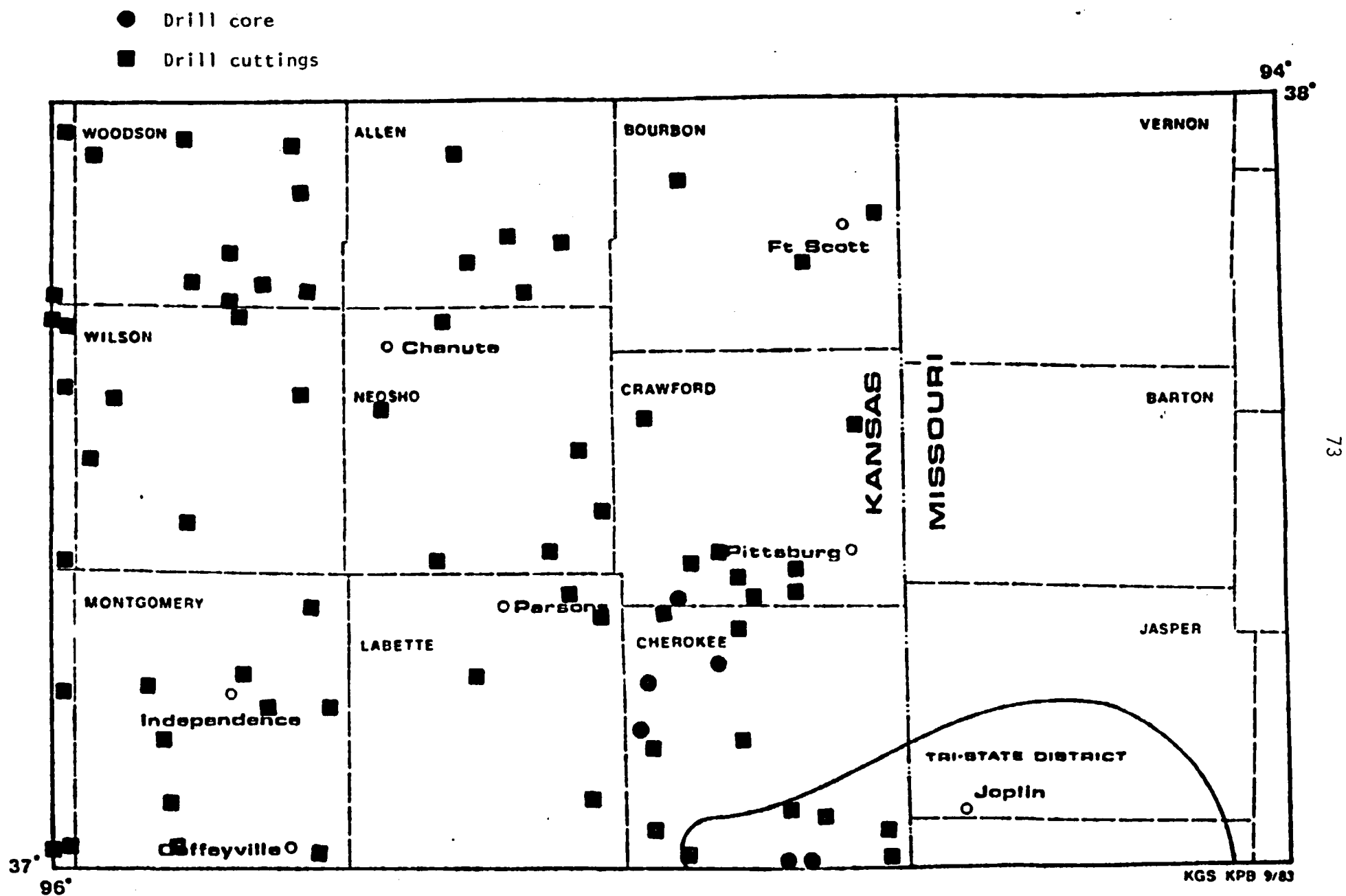


Figure 1. Location of Drill Holes Sampled

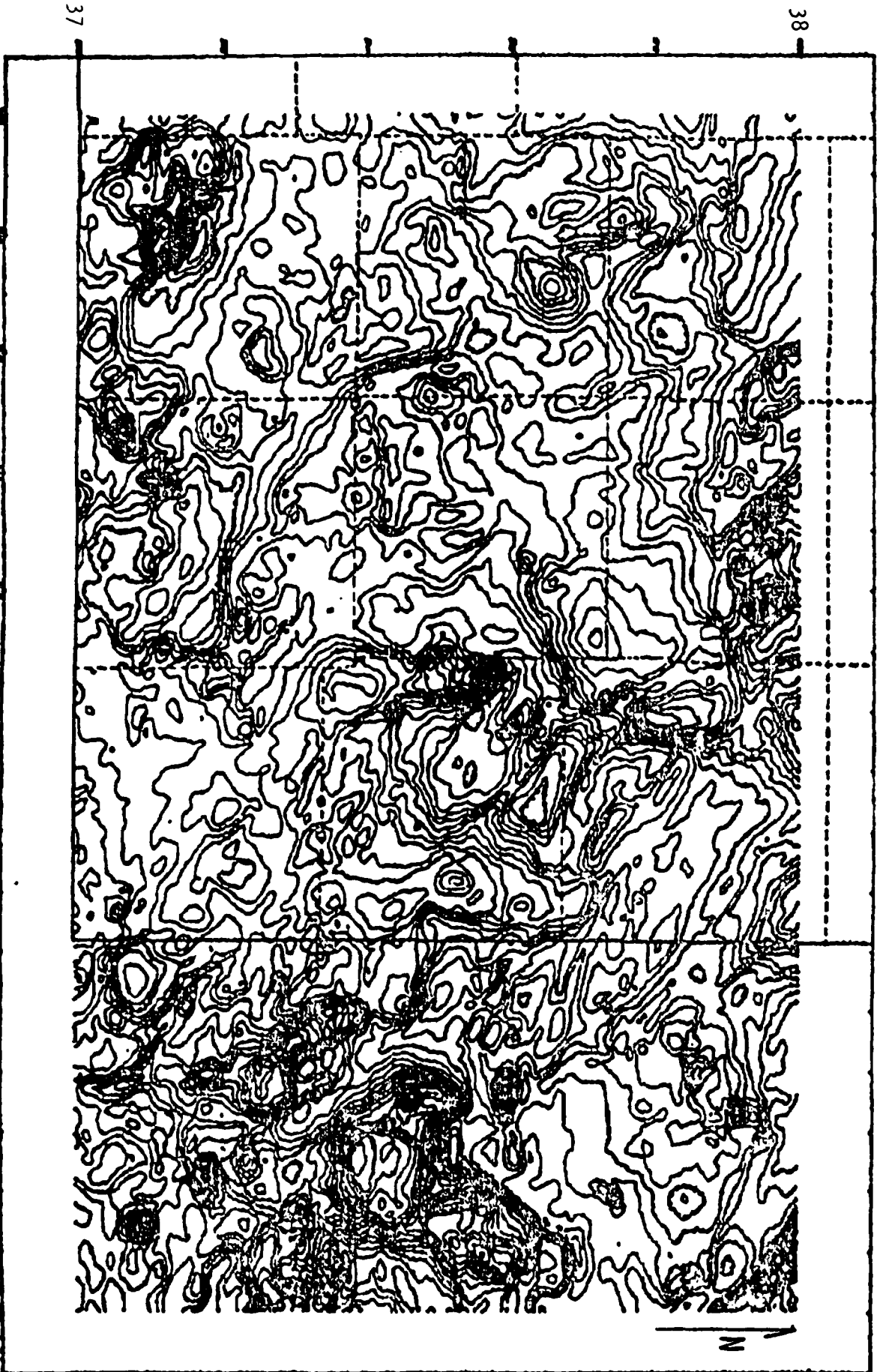


Figure 2. Preliminary Aeromagnetic Map of the Joplin Quadrangle

Figure 3. Preliminary Gravity Map of the Joplin Quadrangle. Station locations are shown.

